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Powered Wheelchair Users Driving Characteristics: a Diagnostic Tool?

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Final report

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Contents

1 Introduction

The use of telemedicine for the remote monitoring of the wellbeing of patients and their response to treatment is becoming increasingly common.

It is proposed that the remote monitoring of a powered wheelchair user's driving characteristics could also be used to monitor the efficacy of some treatments (e.g. Botox to reduce upper limb spasticity) and the need to adapt that treatment to changes in the patient's condition.

Moreover, analysis of the user's driving characteristics could indicate the need for a review of the wheelchair prescription or the need to reprogram or reconfigure the wheelchair as the user's condition changes - for example reprogramming joystick sensitivity as upper limb range of movement decreases.

This information would also help to support feedback from the users themselves, especially if they had intermittent episodes when they had difficulties operating the wheelchair.

Knowing that there is evidence to support their request for additional help could increase the user's confidence in driving and, ultimately, their quality of life.

Therefore the purpose of this feasibility study is to investigate the hypothesis that the way in which each user drives their powered chair can be used as a diagnostic tool.

By collecting and analysing data from the wheelchair, the aim was to evaluate the hypothesis that the user's driving characteristics can provide information about:

- Wellbeing of user
- Impact of medication
- Long term changes in wellbeing/progression of condition
- Whether the powered wheelchair (PWC) is configured suitably for the user or requires further programming

In order to answer this question, a clinical trial was carried out by East Kent Hospitals University NHS Foundation Trust and Sussex Community NHS Foundation Trust from October 2018 to July 2019. HRA Approval [IRAS 235049] was received in January 2018.

The goal of this preliminary report is to present how the data collected and analytical tools used could bring some support to the hypotheses that **the way in which each user drives their powered chair can provide relevant information to healthcare professionals to help make better diagnosis and powered wheelchair prescription.**

2 Powered Wheelchair User's Driving Characteristics

The user's driving characteristics will depend on several factors. For example on user environment, wellbeing, impact of medication, level of alertness, upper limb impairment, postural stability and pain.

For the study purpose, the following data are recorded:

- The daily use of the wheelchair
- Location
- Chair speed
- Joystick movements
- Impact with objects

3 Hypothesis on how this information might be used

Four examples will be given.

3.1 Changes in user wellbeing – By monitoring joystick deflection

Joystick range of movement will depend on the user's physical strength.

A user with Motor Neurone Disease progressively loses upper limb strength. This is reflected in the reduction in distance they can deflect the joystick, increasing asymmetry in that movement and in how they generate that movement.

As limb strength and range of movement decrease with time they will not be able to obtain full joystick deflection with a standard joystick. This progression can be such that the user can drive the chair in the morning, but not in the afternoon. This loss of strength and any asymmetry in that strength will be visible in a joystick deflection plot.

The powered chair can be reprogrammed to increase joystick sensitivity or a joystick with lower activation force provided.

Changes in the user's range and symmetry of movement will also provide some indication of the efficacy of any medication prescribed to improve upper limb range of movement.

It is hoped that such monitoring will help the user to maintain independent mobility for longer.

3.2 Changes in User Wellbeing – By monitoring the number of collisions

An increase in the number and severity of collisions may indicate that the user is having increasing difficulties in controlling the chair. This could be due to the impact of medication – e.g. hay fever tablets making the user drowsy – or a more significant change in wellbeing.

The hypothesis is that each type of collision will have a specific signature. For example running up and down a kerb will have a different signature from striking a wall or doorpost or crossing a pothole in the pavement/road.

If it is possible to distinguish between unintended and intended events, then this information could be used to monitor the safety of a user, improvement in their driving with treatment or even improved safety when using a powered chair with driving assistance.

3.3 Impact of Medication - Smoothness of joystick movement

Smoothness of joystick movement provides some indication of the user's fine motor control.

For example a user with upper limb spasticity will tend to have ataxic movements. This can reduce their ability to safely and confidently drive their powered chair.

Botox treatment can improve fine motor control and reduce the ataxic movements.

Measuring joystick movement smoothness should give an indication of the impact of that treatment

As the effect of the Botox declines there will be an increase in the severity of the ataxic movements. This will be reflected in movement smoothness. The user can then be recalled for another treatment session.

3.4 User Confidence – Level of Carer Assistance

The amount of time that the carer drives the chair [using an attendant control] can be an indication that the user is losing confidence to drive in some environments e.g. outdoors, in crowded environments or crossing roads. It may be possible identify the causes and to deal with the issues. This will help to restore the user's confidence and independent mobility as well as decrease their dependence on their carer.

4 Clinical Trial Methodology

4.1 Powered Chair Data

The participants consented to the placing of a small data recording box on their wheelchair, usually for a period of 5 or more days. The data recorder is a small sealed unit, (white box in Figure 1).

Figure 1: Data recording system placed on a user's wheelchair

It was mounted securely without affecting the operation of the wheelchair nor requiring physical changes to the wheelchair frame or the seating system. It was interfaced to the powered wheelchair data bus between the power module of the wheelchair and the joystick. Its presence did not affect the operation of the chair.

This system records data from the joystick [deflection and profile], from an inertial measurement unit, which contains a three-axis accelerometer, gyroscope and magnetometer, from a real time clock and from a GPS system.

It was found that there was a fault with the decoding of the data from the real time clock [RTC]. All recording units presented activity between 00:00 and 03:00 hrs if the participants were active after 20:00hrs, but no data from 20:00 hrs onwards. A correction of an additional 20:00hrs is required. The RTC is also 37minutes in advance of the actual time. This was confirmed by comparison of RTC with estimated times in the Daily Diary and with the GPS time stamps.

All data was stored in a SD card. It is also possible to store the data in a secured database in the cloud (Figure 2). For this option, a tablet with WiFi and GSM connectivity is used.

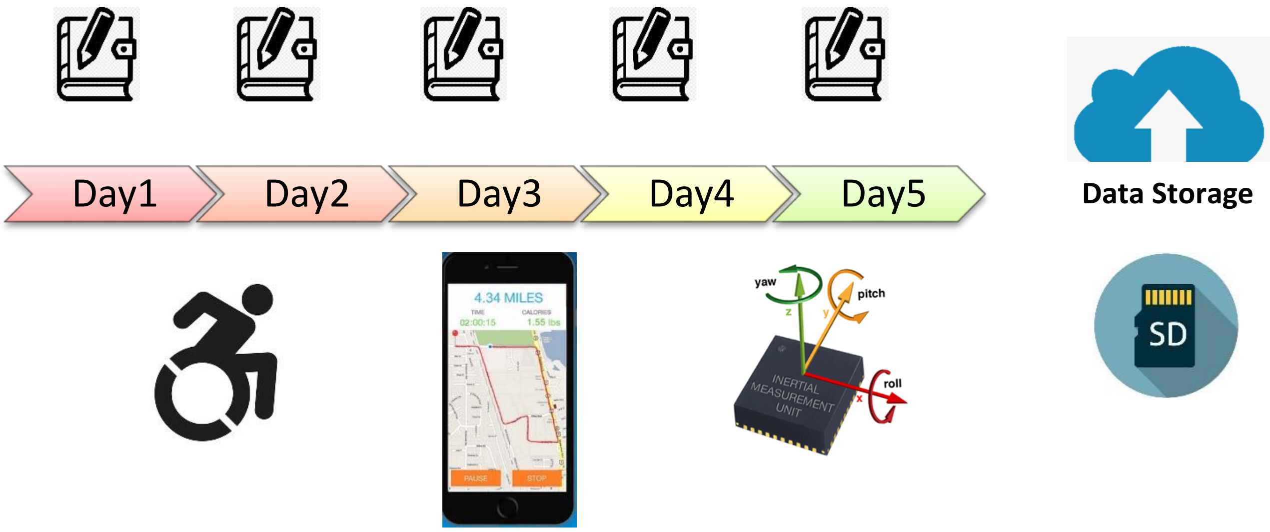

Figure 2: Data collection and storage over trial period

Software was developed to analyse the data to provide information on the use of the joystick and of the wheelchair.

4.2 Participant Diary Record

The participant [powered chair user] was requested to fill out a daily record [Daily Diary] of their wellbeing, medication and location throughout the day. At this stage of the trial the information in the diary is very important as it is used to correlate the recorded powered wheelchair data with the user's diary record.

Wellbeing scores are defined as follows

Health		Pain		Alertness	
Number	***Meaning***	***Number***	***Meaning***	***Number***	***Meaning***
1	Very Well	1	None	1	Hyper alert
2	Well	2	Mild	2	Wide awake
3	All right	3	Moderate	3	Awake
4	Unwell	4	Very Severe	4	Sleepy
5	Very unwell	5	Unbearable	5	Very Sleepy

Table 1: Wellbeing Scores

5 Preliminary Data Analysis

The data recorded over the trial period has been analysed to investigate the hypothesis that identification of user driving patterns can be relevant as a diagnostic tool. Some of the parameters of interest are as follows.

5.1 Powered Wheelchair Use

5.1.1 Activity Patterns

The time that the chair is powered up, driven and actuators used [e.g. seat recline and tilt] over each day is extracted from the recorded data. Short and long-term changes in pattern of usage may indicate changes in user wellbeing, suitability of the powered chair as well as other variables such as the impact of the weather and other events in the user's life.

5.1.2 Wheelchair Profile Use for Driving and Actuators

A powered chair can have up to 5 speed settings [profiles] for driving in different environments. For example profiles 1-3 for use in confined spaces and 4-5 for more open spaces and outdoors.

The way in which the profiles are used can provide information about how well the user is coping with the chair and how well the chair is set up.

The use of a proprietary data bus interface makes it possible to record joystick deflection, profile setting and whether the chair is being driven or the actuators are being used. It is not possible to identify which actuators, if present, are being used.

Monitoring the patterns in the use of actuators could also be used to indicate user wellbeing and comfort.

5.2 Joystick Deflection

5.2.1 Scatter Plot

Joystick deflection scatter plots contain information about the user's upper limb range of motion, symmetry of movement, strength and fine motor control.

Figure 3 shows a typical scatter plot over a period of a few seconds. The restriction of joystick movement to a diamond shape is caused by the presence of a restrictor plate in the joystick module.

The restrictor plate limits the turning speed to a safe level when moving in the forward or reverse direction, thus reducing the risk that the chair may overturn.

In the plot of figure 3 it can be seen that the user has sufficient range of movement and strength to obtain full deflection in all directions.

This will not be the case for some users. For example, users with advancing Motor Neurone Disease or Muscular Sclerosis will show a reduction in range of movement and an increase in movement asymmetry over time. This reduction in joystick movement and increase in joystick movement asymmetry may be caused by a reduction in user strength, a reduction in range of movement or a combination of both.

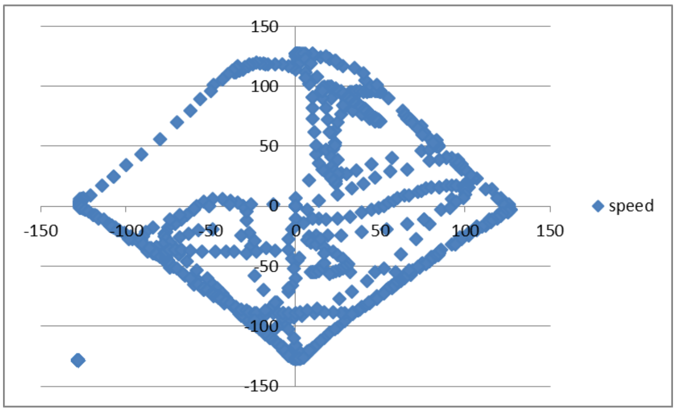

Figure 3: Joystick scatter plot

It is also important to remember that the shape of the scatterplot will be affected by the presence of a restrictor plate in the joystick module and by the joystick programming.

In this trial Dynamic Control DX2 joystick systems were used by the participants.

For these modules the following parameters can modify the chair response to joystick movements.

Short Throw Travel

Default: 100 %   Range: 100 - 200 %

Normally a DX joystick will output a 100% Joystick Deflection signal when the joystick is pushed as far as it can mechanically go (for example when it hits the restrictor plate).

Short Throw Travel increases the joystick gain (output/input ratio) so that less movement of the joystick is required to generate full output. Once the output is at maximum, further movement of the joystick will not result in any further increase in output.

Increasing the joystick gain can be useful in two situations:

1) A small gain increase (up to 105% or 110%) makes sure that a 100% deflection signal is possible in situations where a joystick has not been or cannot be calibrated correctly

2) A large gain increase (up to 200%) allows users with very little hand movement retain full proportional control.

The manufacturer gives the following warning**:** If Short Throw Travel is set to a high value, *the mechanical restrictor plate may not anymore restrict the joystick before its output reaches 100%*. This can cause a situation where the joystick demands full forward speed and full turning speed at the same time, which can be dangerous. For this reason it may be necessary to reduce Short Throw Shape to shave the corners off the 'square of movement' that a high Short Throw Travel value has created.

Short Throw Shape

Default: 200 %   Range: 100 - 200 %

Short Throw Shape shaves the corners off the 'square of movement' that a high **Short Throw Travel** value has created. To achieve an effect similar to that of an octagonal restrictor plate, use a value of 150%. An example of this can be seen in figure 6.

One disadvantage, however, of Joystick deflection scatter plots that have a high density of data points is that it is not always easy to identify where the majority of the displacements are located.

This information may be of use when identifying asymmetry in movement or an imbalance in powered chair motor drive.

An alternative to the joystick displacement scatter plot is the heat map.

5.2.2 Heat Map

The initial assessment in this pilot study used a fairly crude break down of the joystick displacement pattern of either a 3x3 or a 4x4 grid.

The format of a 4x4 grid is shown in Figure 4.

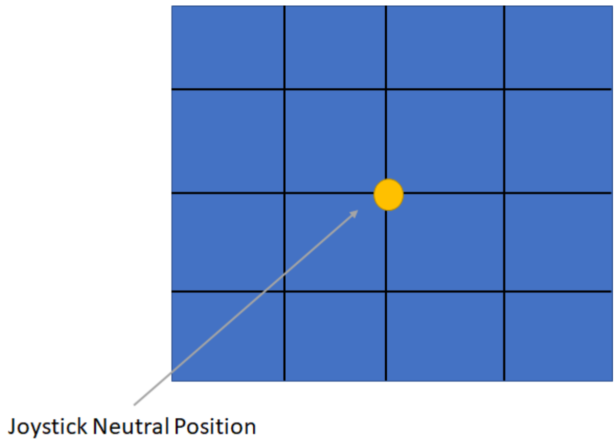

Figure 4: Joystick Deflection Heat map

Each cell represents a range of joystick movements.

The number in each cell to represents the percentage of activity time the joystick is in that cell for a specific recording period.

An example for a user driving a chair is shown in Table 2 below.

1.3	6.4	7.1	2.3
5.1	9.1	9.6	4.9
4.5	8.4	8.1	6.1
2.6	6.6	5.8	1.1

Table 2: Example of Joystick Deflection Heat Map

This example indicates that the user can achieve the full range of joystick deflections. The grid activity numbers indicate that the user is manoeuvring the chair in forward and reverse directions, with approximately the same time spent in both forward and reverse movements.

Note that in this heat map the presence of the joystick restrictor plate is not taken into account. This shortcoming of the grid representation will rectified in future analysis.

5.3 Upper Limb Movement Smoothness

Upper limb movement smoothness is one measure of limb function. For example, spasticity can result in ataxic movements or some conditions, such as Parkinson's, result in upper limb tremor. The measurement of joystick movement smoothness could provide diagnostic information about the progression and treatment of such conditions.

The Normalised Jerk Score [NJS] and Movement Unit Number [MUN] are two means of monitoring the effect of these conditions on joystick movement and, perhaps, the impact of medication.

The recorded joystick displacement data permits the estimation of these measures.

In this pilot the use of NJS will be investigated. It is noted that this may not be the most appropriate measure of smoothness – but is a starting point.

6 Pilot Study Results

Because this is a novel study the analysis software and evaluation of the initial analysis is still in progress.

The following sections will present some of the initial findings for three of the participants to support the hypothesis that monitoring a user's driving characteristics could have diagnostic value.

One participant [UK-SC-P001] had a chair with recline, tilt, elevating leg rests and a seat riser, the second [UK-SC-P003] had a chair with tilt, recline and seat riser actuators and the third [UK-EK-P006] had a chair with drive only.

6.1 Participant 1 UK-SC-P001

6.1.1 Introduction

This participant has tilt, recline, elevating leg rests and seat riser actuators. The chair had 5 profiles.

6.1.2 Powered Wheelchair Activity Patterns

Joystick activity [driving and actuator use] over the week in shown in able 3.

Trial Day	Day of the week	Total joystick activity (min)
Day 1	Tuesday	23.4
Day 2	Wednesday	30.1
Day 3	Thursday	8
Day 4	Friday	15.2
Day 5	Saturday	49
Day 6	Sunday	25.9
Average (min)		25

Table 3: EK-SC-P001 Daily Use of Powered Chair

As can be seen the use of the chair varies throughout the trial period. One reason for this was the changeable cold and wet weather over that period, especially for day 3.

User data throughout Day 5 was broken down into three periods and the analysis for part of Day 5 is presented in Tables 4 and 5 below. Table 4 presents the total time the chair was occupied and the time that the chair was driven or actuators adjusted. Table 5 presents the percentage of time the joystick was active when the chair was occupied.

Time Period	Total time (mm:ss)	Active time (mm:ss)	Actuators Activated (mm:ss)	Driving (mm:ss)	Prof 1 (mm:ss)	Prof 3 (mm:ss)
11:45-12:25	40:00	06:16	06:04	00:12	00:12	0.0
12:26-13:44	78:00	08:46	02:35	06:11	01:02	05:09
13:45-17:36	231:00	25:17	11:19	13:58	00:10	13:48
Total	349:00	40:19	19:58	20:21	1:24	18:57
Percentage Active		13%				

Table 4: UK-SC-P001 Time in chair

Time Period	% Active	Actuators	Driving	Prof 1	Prof 3
11:45-12:25	16%	97%	3%	100%	0.0%
12:26-13:44	11%	29%	71%	17%	83%
13:45-17:36	11%	45%	55%	1%	99%
Average	**13%**	**57%**	**43%**	**39%**	**61%**

Table 5: UK-SC-P001 Percentage of time using actuators, driving and profiles used when driving.

Although the duration of the time periods differ, the percentage of time the joystick is active remains roughly the same.

This could be one parameter in the typical usage pattern of this participant.

Further analysis is required to investigate the relative use of the joystick to drive and to control user posture/comfort.

More detailed examination of this data for each period now follows. The data recorded by the system was correlated with that from the Daily Diary and a basic joystick heat map presented.

6.1.2.1 Period 1 11:45-12:25

The user is indoors in a confined space [Bathroom & Lounge] as recorded in the Daily Diary and indicated the use of profile 1. The recording period is 40 minutes.

The Joystick is active for 16% of PWC power on time.

- Driving for 12 seconds [3% of joystick activity],
- Actuator adjustment for 6 minutes [97% of joystick activity].

Table 6 presents the heat map for joystick activity when driving the chair.

The participant has selected profile 1 [low speed]**.** The chair will drive forward at 2.4km/h [0.7m/s] at full deflection and 1.8km/h in reverse.

0	0	0
0	91.4	0
0	8.6	0

Table 6: UK-SC-P001 Day 5, Period 1. Driving Activity – Profile 1

Table 7 presents the use of the joystick to control the actuators.

0	31	0.2
0.9	33.9	1.5
1.3	31.1	0

Table 7: UK-SC-P001 **Day 5, Period 1. Actuator Activity**

In this time period 97% of joystick activity [6 min] is for actuator control. The actuators are controlled by forward and reverse movements, and do not require any deflection to the left or right.

Activating the actuator only requires movements in the forward and reverse directions. The heat map indicates that the participant has good upper limb control as there are only small deviations out of the forward- reverse axis.

One question that arises was whether this level of actuator activity is normal or is it an indication that the participant is uncomfortable and therefore continually adjusts the seating position? If that is the case then a seating assessment may be required.

However, the participant did not report any issues with pain throughout the week of the study.

6.1.2.2 Period 2 12:26 -13:44.

According to the diary the participant is spending time in the lounge and some in the kitchen. The PWC is on for 1hr 18 min. The joystick is active for 8 min 46 sec, or 11% of PWC on time:

- Actuators are active for 2 min 25 sec, or 29% of active joystick time.
- The participant drives for 6min 11 sec, or 71% of active joystick time.

The participant drove in profile 3 -a higher speed setting - for 5 min 9 sec, probably when in the lounge.

The joystick displacement heat maps for driving and actuator activation are as follows.

The participant has selected profile 1 [low speed]**.** The chair will drive forward at 2.4km/h [0.7m/s] at full deflection and 1.8km/h in reverse.

1.5	15.0	3.6
11.5	47.9	4.5
1.2	11.1	3.8

Table 8: UK-SC-P001 **Day 5, Period 2. Driving Activity – Profile 1 Joystick Displacement Heat Map.**

Full range of joystick movement is evident. The pattern could well be indicative of the need to carry out many fine manoeuvers at lower speeds in the confined kitchen area.

The participant has selected profile 3. The chair will drive forward at 3.6km/h [1m/s] at full joystick deflection and 2.5km/h in reverse.

0.8	8.3	1.0
4.8	73.9	2.7
0.0	7.8	0.7

Table 9: UK-SC-P001 **Day 5, Period 2. Driving Activity - Profile 3 Joystick Displacement Heat Map.**

More time is spent in profile 3 than 1. Presumably when driving in the lounge. This is indicated by the increased turning activity in Tables 8 & 9.

Actuator Activity

0	15.8	0
0.3	66.4	0.6
0	16.9	0

Table 10: UK-SC-P001 **Day 5, Period 2. Actuator Activity**

The proportion of actuator activity is reduced compared with Period 1 [29%/97%]. Joystick control is good as the majority of movements are in the forward/reverse axis.

There is no data in the Daily Dairy to help understand why this is. Nevertheless the user is still spending two and a half minutes in an 80 minute period adjusting seat position.

Is this an indication that the user is not comfortable and really does need to continually adjust posture? Or is it normal?

6.1.2.3 Period 3 13:45 -17:36

The user is in the lounge and reports good health and no pain. The PWC is on for 3h 51min.

The joystick is active for 25 minutes 17 sec or 11% of monitoring period.

This proportion of active time seems to be roughly consistent across all three time periods. Even though those periods are of differing durations [40, 70 and 231minutes]

- Driving for 13min 58sec or 55% of active time. 99% of driving activity in profile 3.
- The actuators are active for 11min 39 seconds [45% of active time].

Is this use of actuators normal, or is it an indication that the user is uncomfortable?

The participant has selected profile 1 [low speed]**.** The chair will drive forward at 2.4km/h [0.7m/s] at full deflection and 1.8km/h in reverse.

0.5	9.1	0.6
6	71.6	4.3
0.2	7.6	0.1

Table 11: UK-SC-P001 **Day 5, Period 3. Driving Activity – Profile 1**

Driving in Profile 1 for 10 seconds. Probably when in the kitchen.

The participant has selected profile 3. The chair will drive forward at 3.6km/h [1m/s] at full joystick deflection and 2.5km/h in reverse.

0.5	9.2	0.6
5.8	72.1	4.2
0.1	7.4	0.1

Table 12: UK-SC-P001 **Day 5, Period 3. Driving Activity – Profile 3**

Driving for 13 min 58sec in profile 3. The increased proportion of deflections in the outer regions of the map indicate that the user is driving in a larger space e.g. the lounge.

Table 13 presents the participants actuator activity.

0	16.4	0
0.5	64.1	0.6
0	18.5	0

Table 13: UK-SC-P001 **Day 5, Period 3. Actuator Activity**

As for the first two periods the map indicates that the participant has good control of joystick as only movement in forward reverse controls the actuators.

6.1.3 Joystick Deflection Scatter Plot

For this participant the Short throw travel and short throw shape are at default value.

Therefore the effect of the restrictor plate is not affected.

Figure 5 presents the joystick deflection scatter plots for a one hour period at the same time of day for days 1, 2, and 3 is shown. Driving and actuator use of the joystick are merged.

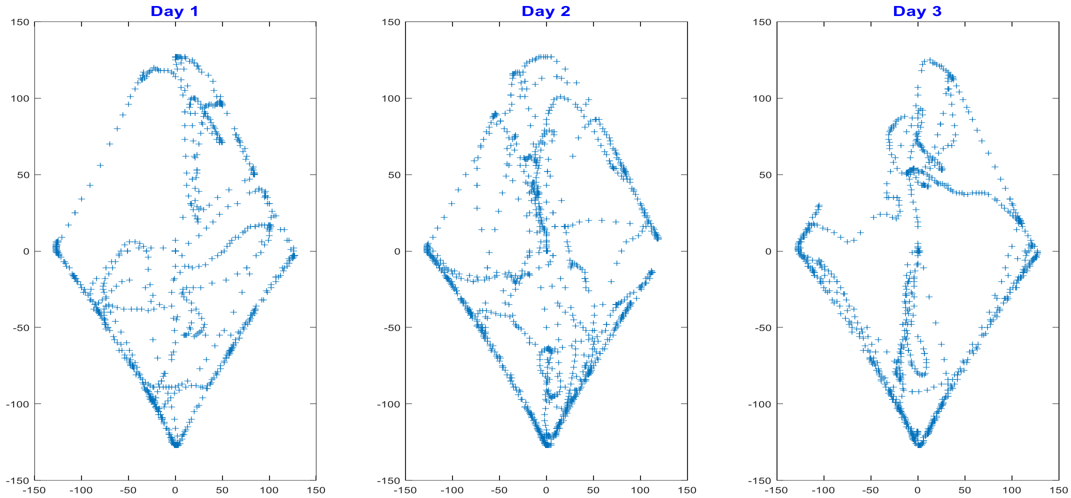

Figure 5: UK-SC-P001 **joystick deflection scatter plot during the same 1 hour period over 3 days.**

The plots show that the participant has adequate upper limb strength, can readily obtain full joystick deflection, has reasonable fine motor control and is taking advantage of the proportional response of the joystick. The daily diary indicates that the participant is driving in a confined space and will want to drive slowly to avoid collisions and therefore selects profile 1.

6.2 Participant 2 (UK-SC-P003)

6.2.1 Introduction

This participant had a powered wheelchair with tilt, recline and seat riser actuators.

The recording box was installed on day 1 and retrieved on day 7.

6.2.2 Powered Wheelchair Activity Patterns

Table 14 indicates when the participant is using the PWC within each hour of the day. The Daily Diary indicated that the PWC was active between 09.00 and from 20:00 hrs onwards.

The Daily Diary indicates activity recorded between 00:00 and 03:00. The participant confirmed that this was not the case as they were in bed and the chair being charged overnight.

It was found that there was a fault with the decoding of the data from the real time clock. All recording units presented activity between 00:00 and 03:00 hrs if the participants were active after 20:00hrs. But no data was recorded for any participant or any recording unit from 20:00 hrs onwards. This is due to a fault in the Real Time Clock data conversion code. A correction of an additional 20:00hrs is required.

The recording device was attached on day 1 – in this case in the afternoon at 13:00hrs.

The recording device was retrieved after 14:00hrs on day 7.

	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day 1	1													1	1					1				
Day 2										1	1			1	1									
Day 3		1											1						1	1				
Day 4	1		1	1								1	1		1	1	1		1	1				
Day 5										1	1							1						
Day 6		1											1		1	1	1			1				
Day 7													1		1									

Table 14: UK-SC-P003 Active periods during study

Table 15 below provides an overview of participant daily activity. This activity includes the time the PWC was powered on and whether the joystick was activated to drive the chair and to adjust the seat tilt/recline.

Trial Day	Day of week	Approximate time in PWC (mins)	% Active	Total Time for Driving (Mins)	% Driving	Total Time Actuator (Mins)
Day 1	Thursday	240	17%	31	76%	10
Day 2	Friday	240	37%	70	79%	18
Day 3	Saturday	240	18%	36	86%	6
Day 4	Sunday	600	11%	50	75%	17
Day 5	Monday	180	53%	82	86%	13
Day 6	Tuesday	240	35%	70	81%	16
Day 7	Wednesday	120	12%	12	86%	2
	Average		**26%**	**50**	**81%**	**12**

Table 15: Daily Overview of Participant SC-P003 joystick activity

The time the participant was in the chair is not known, only the hours in which there was joystick activity. Therefore average activity time is of less use than actual activity time. An overview of the participant's daily use of the chair is given in table 16.

Wellbeing score definitions are found in Table 1

Recording Day [Diary Recorded Day +1]	Joystick activity (Mins)		Location M/A/E	Wellbeing Scores		
	Driving	Actuator		Health M/A/E/N	Pain M/A/E/N	Alertness M/A/E/N
Day 1	31	10	Installed – no diary entry			
Day 2 [Friday]	69	18	Work outdoor/work till16:00/Lounge-dining/bed	1/1/1/1	1/1/1/1	1/1/1/1
Day 3	36	6	Bedroom-Lounge all day	1/1/1/1	1/1/1/1	3/3/3/3
Day 4	50	17	Outdoors/outdoors/home by 16:00/Bed	1/1/1/1	1/1/1/1	1/1/1/4
Day 5	81	13	Work/work/Lounge/Bed	4/4/4/4	1/1/1/1	4/4/4/4
Day 6	70	16	Bed-Lounge all day	4/4/4/4	1/1/1/1	4/4/4/4
Day 7	12	2	Recording Device removed			
Average:	**50**	**12**				

Table 16: Overview of UK-SC-P003 Daily Activity

The results indicate that the participant usually uses the actuator [tilt, recline and seat riser] for more than 10 minutes every day. The user usually spends more than 50 minutes driving on a daily basis.

This activity could potentially be used to indicate the level of use of the wheelchair and highlight changes in joystick use throughout the day and week (for example Day 3). A decrease in activity could potentially highlight change in the user's environment, access levels or state of well-being, which can be validated against their daily diaries.

However, it can be seen from Table 16 that for this participant changes in location or alertness levels did not impact on time sent driving the chair.

6.2.3 An overview of profile use.

The user had five profiles activated. Profiles 1-3 would typically be used for indoor and confined spaces. Profiles 4-5 for use outdoors and in less constricted places e.g. a hall or long corridor.

Table 16 shows the number of minutes each wheelchair profiles was used for driving during the trial period.

This usage pattern will provide an understanding of which profiles are mostly used and whether specific profiles are used in particular environments or conditions.

An atypical use of a particular profile may then provide an indication of a user's wellbeing.

Table 17 shows the use of the 5 profiles when driving the chair over the trial period.

Hour	Day 1					Day 2					Day 3					Day 4					Day 5					Day 6					Day 7				
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
0					10														3	10															
1																														15					
2																																			
3																				3															
4																																			
5																																			
6																																			
7																																			
8																																			
9										3															6										
10									11	0.1															38										
11																																			
12															25				2	12										11					4
13				1					6																										
14		0.2		6	14				9	40							0.1			7										12					8
15																	0.1													11					
16																	1			7										15					
17																									37										
18											0.1									4															
19											1			10						1										6					
20																																			
21																																			
22																																			
23																																			

Table 17: UK-SC-P003 driving use of wheelchair profiles

Profile use over the 7 days is shown in Table 18 below.

Profile	1	2	3	4	5
Minutes Active	1.1	1.4	0	48	299

Table 18: Profile use over trial period

The data of Tables 17 & 18 shows that profile 5 was the participant’s most frequently used profile, irrespective of location.

The chair programming shows that the maximum permitted forward speed of 6km/h [1.7m/s] was available in profile 5. The maximum reverse speed in profile 5 was approximately 0.6m/s

The use of profile 5 indoors in confined areas indicates that this participant is an experienced driver with good fine motor skills. Or that they did not like to change profiles and accepted a higher risk of collisions.

Analysis of the IMU data will be carried out to investigate whether there were any collisions.

Participant UK-SC-P003 makes less use of the actuators than UK-SC-P001, possibly because leg risers are present for UK-SC-P001 and are used to maximise comfort in the chair.

6.2.4 Joystick Deflection Scatter Plot

A plot showing the joystick deflection scatter plots for a one hour period at the same time of day for days 2 and 4 are shown in figure 6. Driving and actuator use of the joystick are merged.

The patterns indicate that the user did not have any difficulties obtaining full deflection in all directions.

The program has Short Throw Shape and Short Throw Travel set at 150%.

This means that maximum output is achieved at about 75% deflection and the restrictor plate will no longer keep turning speeds to a safe level

This short throw setting shaves the corners off the 'square of movement' that the high Short Throw Travel and results in an effect similar to that of an octagonal restrictor plate.

The effect of these settings results in the shape seen in the following scatter plots.

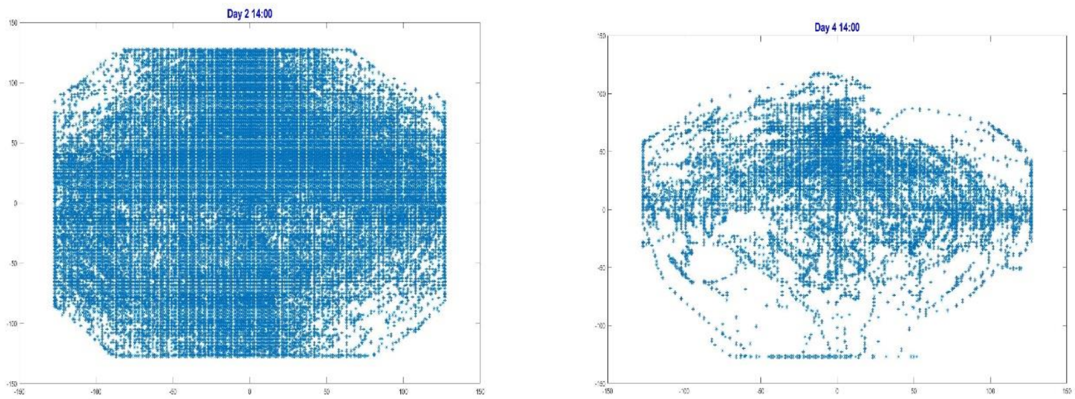

Figure 6: SC-P003 Joystick deflection scatter plot over same 1 hour period over 2days.

It can be seen from Table 17 and the density of the scatter plots that the participant was less active on day 4 between 14:00 and 15:00.

6.2.5 Joystick Deflection Heat Map Overview

Day 1				Day 2			
0%	24%	11%	1%	1%	20%	9%	1%
6%	22%	20%	7%	6%	14%	15%	10%
3%	2%	1%	2%	4%	4%	3%	4%
1%	1%	1%	0%	1%	5%	3%	0%
Day 4				**Day 6**			
1%	7%	3%	0%	1%	36%	18%	0%
8%	26%	23%	8%	5%	17%	10%	4%
3%	5%	7%	8%	3%	2%	1%	0%
0%	1%	1%	0%	0%	0%	0%	0%

Table 19: UK-SC-P003 Day 1, 2, 4 and 6. Hours 14:00. Driving Activity – Profile 5

Note that

- Usually the use of profile 5 indicates that the participant is in more open spaces. Therefore, there will probably be less reversing activity. However for day 6 the participant was indoors and only used profile 5 throughout the day.
- There is a bias to the left. This indicates that there may be an imbalance in the motor set up.

Day 1				Day 2			
0%	33%	8%	0%	0%	23%	13%	0%
1%	3%	2%	1%	2%	12%	5%	2%
0%	2%	3%	0%	0%	4%	2%	0%
0%	26%	21%	1%	0%	19%	18%	0%
Day 4				**Day 6**			
0%	0%	0%	0%	0%	38%	24%	0%
0%	0%	0%	0%	4%	18%	13%	1%
0%	1%	0%	0%	0%	1%	0%	0%
0%	98%	1%	0%	0%	0%	0%	0%

Table 20: UK-SC-P003 Actuator activation. Day 1, 2, 4 and 6. Hour 14:00.

Note that in all the heat maps there is also a bias to the left as for driving. However, actuator activation only relies on forward and reverse displacements of the joystick.

This may indicate an asymmetry in the participant's upper limb movement.

6.2.6 Normalised Jerk Score

Movement smoothness may provide information of upper limb function or dysfunction.

Normalised jerk score is one measure of movement smoothness.

Hour	Normalised Jerk Score
12	12.60
14	11.88
16	10.02
18	10.39
20	6.99
23	7.63
Average	9.92

Table 21:UK-SC-P003 Day 4. Profile 5. Normalised Jerk Score over the day.

Hour	Normalised Jerk Score
21	8.14
12	11.65
14	17.95
15	15.66
16	9.14
19	7.04
Average	11.6

Table 22: UK-SC-P003 Day 6. Profile 5 Normalised Jerk Score over the day.

Participant UK-SC-P003 did not report any issues with upper limb function and was not taking any medication that might affect this function.

Note that the times have been corrected to include activity from 20:00hrs onwards.

Movement smoothness has not changed over the measurement period. The participant did not report any issues with movement smoothness.

6.3 Participant 3 [UK-EK-P006] – Trial 2

6.3.1 Introduction

This participant had a chair without actuators for tilt/recline adjustment.

The chair is used intermittently throughout the day. The participant transfers to and from the chair as needed.

After the first trial it was recognised that the participant's chair required reprogramming because it would not turn when stationary in profile 1. The chair was reprogrammed to resolve this issue and a second trial of 14 days was run.

However the participant reported that although the chair performance improved, there was an imbalance in the motor drive. The participant reported that this was evident when driving outside and a bias to the right was required in order to drive in a straight line. This bias was not dependent on pavement camber or direction driving along the same pavement.

Because of the participant's environment and use of the chair and the need to reprogram the chair, the following areas were to be investigated.

The results from the second trial are reported.

6.3.1.1 Impact of indoor environment on driving patterns

The participant's flat layout and daily driving path indicated that typical indoor driving would give asymmetric displacement joystick displacement patterns. This would be demonstrated by less activity with reversing to the right.

As for all participants it is expected that the environment will also affect selection of profiles.

For example in confined spaces profiles 1-3 [low speeds] might be expected. In open spaces profiles 4-5 would be expected.

6.3.1.2 Characterisation of Impacts

The goal was to extract data from the Inertial Measurement unit to begin the characterisation of powered chair interaction with the environment e.g. passing down and up kerbs or colliding with objects such as doorposts. This work is still in progress.

6.3.1.3 Incorrect Programming of the Powered Chair

During the first trial profile 1 was used to drive the chair indoors. However the user was unable to turn the chair from stationary when using profile 1. Therefore profile 2 was used in those circumstances.

The chair was reprogrammed so that profile 1 could be used to turn the chair when stationary. The trial was repeated for another 18 days.

After the second trial the participant reported that when driving outdoors there was a drift of the chair to the left. The joystick had to be displaced 20-25^{O} to the right to compensate for this drift.

Analysis of the data should indicate that there was an issue with using profile 1 when indoors during the first trial and that this problem had been reduced after reprogramming.

The issues of motor imbalance will be evident in the heat maps when driving outdoors.

6.3.1.4 Wellbeing Scores record in the Daily Diary

This participant provided a comprehensive record of wellbeing scores throughout each day.

The day was divided into rough periods;

Morning [Getting up to lunch]; Afternoon [Lunch to supper/tea]; Evening [Suppertime to bed]; Night [going to bed to getting up].

The wellbeing score definitions are presented in the Table 1 at the beginning of this report..

6.3.2 Powered Wheelchair Activity Patterns

		00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
03/05/2019	Day 1		1	1											1			1		1	1				
04/05/2019	Day 2		1													1			1		1				
05/05/2019	Day 3		1							1								1		1	1				
06/05/2019	Day 4		1																		1				
07/05/2019	Day 5		1												1	1	1	1	1	1					
08/05/2019	Day 6	1	1										1	1	1		1			1	1				
09/05/2019	Day 7		1								1	1		1	1				1	1	1				
10/05/2019	Day 8		1	1												1	1		1	1	1				
11/05/2019	Day 9	1	1							1										1	1				
12/05/2019	Day 10		1																	1	1				
13/05/2019	Day 11	1	1								1										1				
14/05/2019	Day 12		1																		1				
15/05/2019	Day 13		1										1	1	1	1	1			1	1				
16/05/2019	Day 14		1																						
17/05/2019	Day 15		1	1												1			1	1	1				
18/05/2019	Day 16			1						1	1						1	1		1	1				
20/05/2019	Day 17		1								1	1	1	1	1				1	1	1				
21/05/2019	Day 18										1														

Table 23: UK-EK-P006 Active periods during study

In this table the active periods are presented for each day of the trial.

Note that the recording times for the period between 00:00 to 03:00 are incorrect. There has been an error in the decoding of the real time clock [RTC] data.

EDUCAT - Output Report

Examination of the Daily Diary record indicates 20 hrs should be added. This timing error is corrected in the data analysis. Activity is reported between 20:00 and 23:00, rather than 00:00 and 03:00hrs

Recording Day	Total Driving Time (Mins)	Diary [Recorded Day +1] M/A/E	Wellbeing Scores		
			Health M/A/E/N	Pain M/A/E/N	Alertness M/A/E/N
Day 1	7	Installed			
Day 2 [4th May]	12	No/15:05 Flat- Apartment block / Flat	3/2/2/2	2/3/3/3	1/2/2/4
Day 3	7	No/16:52 Flat/Flat until 21:51	2/2/2/3	2/1/1/3	2/4/3/4
Day 4	9	No/No/ Apartment block 19:47-21:47	3/2/3/3	2/3/3/3	2/2/2/4
Day 5	60	No/13:50 flat -15:25 Outdoors Town centre/Flat til 21:49	3/2/2/3	2/2/2/3	1/2/2/4
Day 6	14	10:45 Flat/Flat Office/Flat til 22:20	3/3/3/3	2/2/3/3	1/1/1/4
Day 7	11	10:16 Flat/Flat –office/flat Apartment block until 21:55	2/2/2/3	2/2/2/3	2/3/2/4
Day 8	69	No/ 14:20 Outdoors/Flat office until 22:25	2/2/2/3	2/3/3/3	1/1/2/4
Day 9	16	No/No/Flat 7 Apartment block	2/2/2/2	3/2/2/2	2/2/2/4
Day 10 [12th May]	3	No/18:26 Flat Office/ Flat -21:58	3/3/3/3	2/3/3/3	1/2/2/4
Day 11	10	No/ 19:25 Flat & Office/Apartment Block 22:00	2/2/2/3	2/2/2/2	1/2/2/4
Day 12	7	No/No/19:47 Apartment block until 21:50	2/2/2/2	2/2/3/2	1/1/2/4
Day 13	39	11:10 Flat /11:15 Outdoors + lunch stop/Apartment Block & Flat till 21:55	2/2/2/2	2/2/3/3	1/1/2/4
Day 14	0	No/No/Nor	2/2/2/2	2/2/2/2	1/1/2/5
Day 15	15	No/14:25 18:26 Apartment block/Flat until 22:38	2/2/2/2	2/2/2/2	2/2/2/5
Day 16	37	No/Outdoors/Flat 7 Office until 22:50	2/3/2/2	2/2/2/3	1/2/2/4
Day 17	0	No/No/No	2/2/2/2	2/2/2/2	1/1/1/5
Day 18	17	10:15 Flat-Apartment block/Apartment Block/Flat Office 21:58	2/2/2/2	2/2/2/2	1/2/2/5
Average	**21**				

Table 24: Daily Overview of UK-EK-P006 activity

Note: Average for when the chair was used. Days 14 and 17 are not included.

Diary column: No=not in chair for that period.

The participant transfers to and from chair throughout day.
No use of chair at night

M=Morning [Getting up to lunch]; A=Afternoon [Lunch to supper/tea]; E=Evening [Suppertime to bed]; N=night [going to bed to getting up]
Days 14 and 17: No chair use.
Day 5, 8 and 16 – extensive use of the chair because the participant was outdoors.

6.3.3 Profile Use

Hour	Day 1					Day 2					Day 3					Day 4					Day 5					Day 6				
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
0																										1				
1	3					1					2		1			4	1	1	1	0.1	1					2				
2	0.1																													
3																														
4																														
5																														
6																														
7																														
8											0.1																			
9																														
10																														
11																										1				
12																										1				
13	1																				2					2				
14						1															4									
15																					0.1	8	13	2	16	3	1	2		
16	1										2											4	2	1	6					
17						5	2	1	1												1	0.1								
18	1										1	0.1									1					1				
19	1					1					1					2										1				
20																														
21																														
22																														
23																														

Hour	Day 7					Day 8					Day 9					Day 10					Day 11					Day 12				
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
0											3										1									
1	2	2	0.1	1		2					2					2					3	1	1	0.1	1	3	1	1	1	
2						1																								
3																														
4																														
5																														
6																														
7																														
8											0.1																			
9	1																				0.1									
10	1																													
11																														
12	1																													
13	2																													
14						2	5	4		10																				
15						4	1	10	0.1	27																				
16																														
17	1					1																								
18	0.1	1				1					2		1			1														
19		1				2					4	1	2	0.1	0.1	1					1	2				1				
20																														
21																														
22																														
23																														

Hour	Day 13					Day 14					Day 15					Day 16					Day 17					Day 18				
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
0																														
1	1					0.1					2										1									
2											1					3														
3																														
4																														
5																														
6																														
7																														
8																0.1														
9																0.1					2	1				1				
10																					3	0.1								
11	0.1	1	0.1	0.1	7																1									
12	1	1		0.1	0.1																0.1	1								
13	0.1																				0.1	1								
14	5	3	4	0.1	11						4	1	0.1																	
15	2															1	1	3	1	13										
16																2	5	0.1		6										
17											1										3	1	0.1	0.1	0.1					
18	2										1						1				1									
19	0.1										1					1	0.1				1									
20																														
21																														
22																														
23																														

Table 25: UKEK-P006 Overview of wheelchair profiles

Profile	1	2	3	4	5
Time [min]	136	48	47	9	84

Table 26: UK-EK-P006 Profile use over Trial Period

The participant uses all the profiles. Inspection of the daily diary indicates that profile 1 is predominantly used when in the confines of the participant's small flat. Profile 2 and 3 used occasionally when in the apartment block and profile 5 when outdoors.

The participant chair could be programmed to have only 3 or 4 profiles.

6.3.4 Joystick deflection Scatter Plots

Short throw travel and Short Throw Shape were at default values. Therefore the effect of the restrictor plate was not affected.

The joystick deflection pattern presented in Figure 7 occurred when the user reported that the majority of driving took place in the flat. This pattern does not indicate that the participant has difficulty in deflecting the joystick into this quadrant.

Because of the layout of the flat it was expected that the joystick deflection pattern would show less activity for right reverse than left reverse manoeuvers.

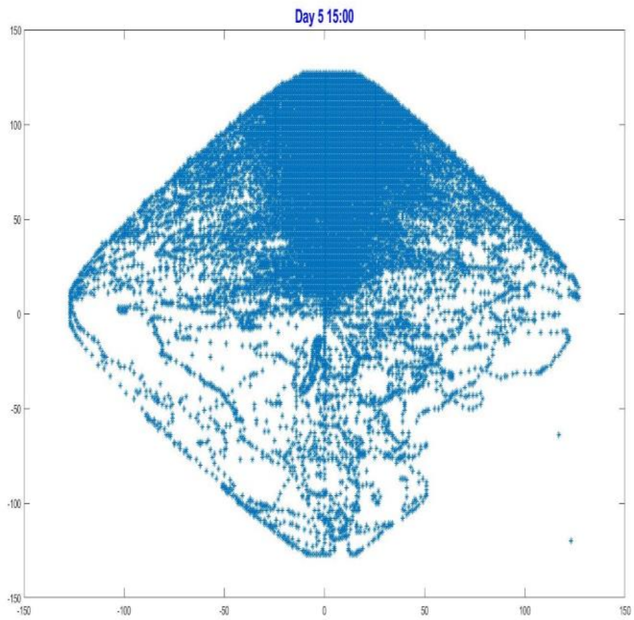

Figure 7: UK-EK-P006 Joystick Scatter Plot. Day 5. Afternoon - Indoors

The user was indoors. The user reported that most of the time was spent moving between living area and study. Reversing to the left rather than the right is the preferred manoeuvre to leave one of the rooms.

The joystick deflection pattern of figure 8 [Day 5 afternoon] indicates that the user does not have any difficulties in deflecting the joystick to maximum travel in the lower right quadrant.

If the plot of Figure 7 was taken in isolation and without understanding of the environment this might lead to a false diagnosis. That is that the participant had issues with upper limb strength and range of motion in the lower right movement quadrant.

Therefore understanding the environment is also important when examining joystick deflection patterns.

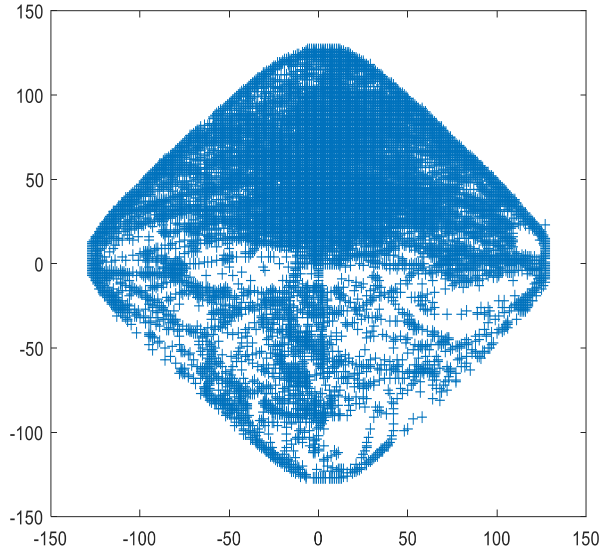

Figure 8: UK-EK-P006 Day 5 Afternoon - in flat and communal area

In this period the participant was also driving in communal areas of the apartment block. Therefore there is relatively more activity for right reversing.

The plot also shows that the participant does not have any difficulties in obtaining the full range of joystick movement.

6.3.5 Joystick Deflection Heat Map

Days 2, 5, 8 and17 have been selected. The Daily Dairy provides the following approximate location and time information.

It is expected that the participant will use profiles 1-3 when indoors and 3-5 when outdoors.

It is expected that there will be more reversing activity when manoeuvring the chair indoors. This will usually occur when using profile 1. When outdoors there will usually be enough space to turn the chair round without needing to reverse.

The Daily Diary information for these days and times is as follows.

Day 2 [4th May] 17:00hrs. Participant indoors in flat

Day 5 [7th May] 15:00hrs. Outdoors – Flat to Town centre

Day 8 [10th May] 15:00hrs. Outdoors

Day 16 [18th May] 15:00hrs. Outdoors

Day 18 [20th May] 17:0rs. Flat and Apartment block.

When outdoors the participant reported that the joystick had to be deflected approximately 15-25^{o} to the right in order to drive in a straight line. This was irrespective of pavement camber.

This imbalance should present itself in the relative time spent with the joystick displaced to the left and right. The imbalance would be expected to be more pronounced when outdoors.

In the following heat maps the average time spent with left and right deviations is also calculated.

When in the flat there will be more reversing to the right than to the left – as shown in the scatter plot of figure 7.

Profile 1				Profile 2				
0%	7%	12%	1%	2%	16%	27%	1%	
2%	9%	13%	5%	6%	16%	13%	6%	**Day 2**
3%	3%	6%	4%	1%	7%	1%	1%	
0%	24%	11%	0%	0%	2%	1%	0%	
L/R	**48%**	**52%**		L/R	**50%**	**50%**		
0%	16%	17%	1%	2%	26%	27%	2%	
2%	7%	9%	5%	5%	15%	5%	5%	**Day 18**
5%	3%	7%	2%	1%	3%	1%	1%	
0%	23%	3%	0%	0%	2%	5%	0%	
L/R	**56%**	**44%**		L/R	**54%**	**46%**		

Table 27: UK-EK-P006 Day 2, 18. Hour 17:00 . Driving Activity – Profiles 1 and 2

Day 2 active for 17 minutes. Indoors in flat

Day 18 Active for 23 minutes. In the flat and around the ground floor of the Apartment block.

It can be seen that for profile 1 there is significant reversing and turning activity compared to the use of the other profiles. This will add a bias to the left deflections which may partially counteract the effect of the motor imbalance.

Profile 3				Profile 5				
0%	28%	42%	0%	0%	18%	75%	0%	
1%	10%	14%	2%	0%	1%	6%	0%	
0%	2%	1%	0%	0%	0%	0%	0%	**Day 5**
0%	0%	0%	0%	0%	0%	0%	0%	
L/R	**41%**	**59%**		L/R	**19%**	**81%**		
0%	32%	31%	0%	0%	21%	25%	0%	
2%	19%	13%	1%	0%	23%	29%	0%	**Day 8**
0%	1%	1%	0%	0%	1%	1%	0%	
0%	0%	0%	0%	0%	0%	0%	0%	
L/R	**54%**	**46%**		L/R	**45%**	**55%**		
1%	25%	37%	0%	0%	21%	44%	0%	
2%	25%	17%	1%	0%	14%	18%	1%	**Day 16**
0%	1%	0%	0%	0%	1%	1%	0%	
0%	0%	0%	0%	0%	0%	0%	0%	
L/R	**54%**	**55%**		L/R	**36%**	**64%**		

Table 28: UK-EK-P006 Day 5, 8 and 16. Hour 15:00. Driving Activity – Profiles 3 and 5

For days 5, 8 and 16 the participant is mainly Outdoors. The heat maps for profile 5 indicate that there is now a significant bias to the right.

This indicates that the imbalance in motor power should be corrected when next programming the chair.

6.3.6 Normalised Jerk Score

The participant had normal upper limb movement without the presence of any tremor.

The jerk sores should then be a measure of normal joystick activity.

The times for 00:00-0400 have been corrected by adding 20hrs.

In gener

Day 5 (07/05/2019)							
NJS							
Hour	**Profile: All**	**Profile: 1**	**Profile: 2**	**Profile: 3**	**Profile: 4**	**Profile: 5**	**Main Location**
13	10.38	10.38	0.00	0.00	0.00	0.00	Apartment block and flat
14	11.20	11.20	0.00	0.00	0.00	0.00	Indoors
15	18.57	0.11	2.95	6.95	1.15	7.69	Outdoors - to town centre
16	15.65	0.00	4.88	3.16	1.95	6.54	Outdoors
17	13.97	12.20	2.16	0.00	0.00	0.00	Flat
18	9.54	9.54	0.00	0.00	0.00	0.00	Flat
21	12.59	12.59	0.00	0.00	0.00	0.00	Flat

Table 29: UK-EK-P006 Day 5. Normalised Jerk Score over the day.

Day 8 (10/05/2019)							
NJS							
Hour	***Profile: All***	***Profile: 1***	***Profile: 2***	***Profile: 3***	***Profile: 4***	***Profile: 5***	**Main Location**
14	*12.0*	*1.04*	*3.99*	*3.38*	*0.00*	*12.01*	Flat/Outdoors
15	*11.5*	*1.04*	*0.30*	*4.23*	*0.04*	*11.87*	Outdoors
17	*8.4*	*8.43*	*0.00*	*0.00*	*0.00*	*0.00*	Flat
18	*9.7*	*9.69*	*0.00*	*0.00*	*0.00*	*0.00*	Indoors
19	*10.08*	*10.08*	*0.00*	*0.00*	*0.00*	*0.00*	Apartment Block
21	*9.45*	*9.45*	*0.00*	*0.00*	*0.00*	*0.00*	Flat
22	*12.34*	*12.34*	*0.00*	*0.00*	*0.00*	*0.00*	Indoors

Table 30: UK-EK-P006 Day 8. Normalised Jerk Score

Day 13 (15/05/2019)							
NJS							
Hour	**Profile: All**	**Profile: 1**	**Profile: 2**	**Profile: 3**	**Profile: 4**	**Profile: 5**	**Main Location**
11	16.0	0.17	2.73	0.68	0.59	16.36	[Flat] Mainly Outdoors
12	7.5	7.86	5.88	0.00	0.41	0.05	Outdoors
13	2.50	2.50	0.00	0.00	0.00	0.00	Outdoors
14	10	2.98	1.80	3.47	0.16	10.56	Outdoors
15	8.51	8.51	0.00	0.00	0.00	0.00	Apartment Block/Flat
18	12.32	12.32	0.00	0.00	0.00	0.00	Apartment Block/Flat
19	4.88	4.88	0.00	0.00	0.00	0.00	Apartment Block/Flat
21	11.39	11.39	0.00	0.00	0.00	0.00	Flat

Table 31: UK-EK-P006 Day 13. Normalised Jerk Score.

12:00 -14:00 – outdoors – around locality. More manoeuvring evident in joystick movements.

At 13:00 many periods of no activity which has supressed the NJS.

Similarly at 19:00 – 75% of time not driving. This results in many periods of zero deflection which will decrease NJS.

The analysis program will be modified to remove data when there is no joystick activity.

Day 18 (20/05/2019)							
NJS							
Hour	Profile: All	Profile: 1	Profile: 2	Profile: 3	Profile: 4	Profile: 5	Main Location
9	8.5	8.52	4.59	0.00	0.00	0.00	Flat/Apartment Block
10	9	9.24	1.70	0.00	0.00	0.00	Apartment Block
11	11.11	11.11	0.00	0.00	0.00	0.00	Flat
12	11	1.54	11.09	0.00	0.00	0.00	Apartment Block
13	8.5	3.27	8.94	0.00	0.00	0.00	Apartment Block
17	6	6.37	3.73	0.27	0.49	1.36	Around Apartment Block/Flat
18	9.23	9.23	0.00	0.00	0.00	0.00	Flat
19	8.49	8.49	0.00	0.00	0.00	0.00	Flat
21	9.61	9.61	0.00	0.00	0.00	0.00	Flat

Table 32: UK-EK-P006 Day 18. Normalised Jerk Score

Participant's pattern is to use profile 1 in Flat, 1 and 2 in the Apartment block and 4&5 Outdoors.

Cannot distinguish between outdoors and indoors using the NJS.

In order to identify tremor it will be necessary to carry out further experiments in OAS trials [O3.1].

May need to use and alternative technique e.g. Fourier analysis, to identify tremor.

7 Conclusion and Further work

7.1 Introduction

The purpose of this study was to evaluate the hypothesis that the user's driving characteristics can provide information about:

- Wellbeing of user
- Impact of medication
- Long term changes in wellbeing/progression of condition
- Whether PWC is configured suitably for the user or requires further programming

7.2 Data recording Unit

A low cost, easy to mount recording box was attached for 5-14 days to the participant's wheelchair to collect data from the wheelchair (joystick, actuators and profiles) as well as from an inertial measurement unit and a GPS unit.

The issues with incorrect clock times were identified and can easily be corrected.

7.3 Participants

Nine users were included in the clinical trials.

The user was requested to fill out a daily record [Daily Diary] of their wellbeing, medication and location throughout the day. This data was correlated with the data analysis.

The initial findings for three of the participants, support the hypothesis that monitoring a user's driving characteristics could have diagnostic value.

7.4 Powered Wheelchair Use

7.4.1 Activity Duration and Patterns

The system can provide information about time of use over specified periods of the day.

Longer term recording will enable any changes in these patterns to be identified.

If these changes are related to changes in user wellbeing then clinical intervention can then be provided.

UK-SC-P001 showed significant actuator activity compared to driving activity. At present there is not enough data to know whether this is typical for that participant, for all participants, or whether there is an issue with comfort and the seating system.

However the analysis has shown that these characteristics can be obtained. The next stage is to refine the analysis software and to investigate how measuring these characteristics can be used to improve the quality of life of powered chair users.

The time each user was active in the powered chair was also measured.

Activity means either driving the chair or using the actuators.

This is a complex measurement.

Some users have to be in their chair all the time as it provides essential posture management.

Some require a powered chair to provide independent mobility.

UK-EK-P006 also has limited mobility and does not always use the powered chair when indoors. One measure of activity is the time spent driving or using actuators.

On average EK-P006 drove the chair for 21 minutes each day over a two week period in the Summer.

UK-SC-P001 Operated the joystick for 25 minutes daily average with 70% driving and 30% actuator use. Though actuator use when indoors dominate driving. As might be expected.

UK-SC-P003 operated the joystick for 62 minutes daily average with 0% driving and 20% actuator use. The increase in driving time is due to using the powered chair to go to work on several days each week.

7.4.2 Profile Use

The extraction of profile data is straightforward.

Analysis of profile use show how well the chair has been set up. Participant, EK-SC-P003, had 5 profiles available, but predominantly used profile 5 in all environments.

Also the reason for only sing one profile could be investigated e.g. analyse whether there are any impacts when using profile 5 within the home.

If there are then the participant may have some issues with the chair and accessing the profiles.

The chair can be reprogrammed to reduce the number of profiles.

7.4.3 Joystick deflection Scatter Plots

These patterns provide information about the user's range of movement and strength.

Changes in the user's ability to use the joystick – for example progressive conditions such as MND or MS - can be monitored.

7.4.4 Joystick Deflection Heat Map

Displaying the joystick displacement with a heat map for both the driving and actuator activity has also been shown to provide information on the user's activity.

Issues with chair set up such as imbalance in motor drive were evident in two of the participants. These imbalances can be corrected by reprogramming the powered chair.

The diagnostic value of this presentation requires further investigation.

7.5 Joystick Smoothness Measure

Normalised Jerk Score was used as a smoothness measure.

The two participants analysed had NJS values of around 10. Whether this is normal for joystick movements requires further investigation.

There is no significant difference between NJS values indoors and outdoors.

The error in estimating the NJS when the joystick is stationary is to be removed.

NJS is one of several smoothness measures.

The most appropriate measure of smoothness is to be investigated.

It may be better to use Fourier analysis techniques to identify tremor.

The value of the smoothness measures in monitoring the efficacy of medication or progression of condition requires further investigation. Participants who have ataxic movements or tremor would be appropriate Subjects. It is hoped to set up clinical trials to continue this investigation.

7.6 Changes in User Wellbeing – By monitoring the number of collisions

Impact and event data has been recorded for a range of scenario.

Participant UK-SC-P003 used profile 5 irrespective of location. Analysis of the IMU data may show whether this choice was through difficulty in changing the profile and in accepting a higher incident of collisions when indoors.

The goal is to be able to identify unintended collisions. The impact of treatment and the provision of driving assistance e.g. collision avoidance, can then be assessed.

The development of algorithms to help analyse this data is now underway. The first stage is to identify the characteristics/signatures of each event. This analysis can then be applied to the data collected in the Stage 1 trial.

7.7 Data Processing Specifications

If a standard laptop is used [i5 processor] it can take up to 24hrs to process the data from a five day recording period. This data then has to be analysed to characterise the participant's driving patterns.

Further development of the software is required to decrease data analysis time and to automate the characterisation of any driving patterns and changes in these patterns.

7.8 Deliverables

7.8.1 Deliverable D.2.3.1. Data analysis

Description of deliverable: *Data analysis using software of D2.1.3, to identify links between driving characteristics, user diagnosis; short and long term changes in wellbeing of user's with progressive condition; impact of treatment on user's condition/symptoms.*

Identification of key physiological parameters related to upper limb movement and user diagnosis.

Refined data analysis techniques to maximise the efficiency of analysis process.

This report has presented the preliminary data analysis for three of the 9 participants.

Because these participants were medically stable over the limited trial period, it has not been possible to identify links between their driving characteristics.

However, the following key parameters identifying user driving characteristics and wellbeing can now be determined;

- Powered Chair Activity patterns
- Profile Use
- Joystick activity
    - Scatter Plots for range of movement
    - Heat Maps for overall patterns
    - Movement Smoothness utilising Normalised jerk Scores

7.8.2 D 2.3.2 Report of conclusions

This Report

7.9 Comments

The initial outcome of this pilot study shows that user's driving characteristics can be obtained.

The participants were all well and expert drivers. Therefore it was not expected to see any changes in driving characteristics over the 5-7 day monitoring period.

One difficulty in analysing the data has been the paucity of information in the Daily Diary, which makes it more difficult to separate the data out in to specific locations within the home.

Therefore participants in follow up trials will be encouraged to provide richer data in the Daily Diary.

The data from all the participants in this pilot study is to be analysed and analysis software developed.

A further study is planned with an updated and improved data recording system that will also transmit the recorded data to the project team server for analysis.

The data processing and analysis software also requires further development ,especially if trials over several weeks are to be run.

8 Contact Details

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