Development of a Face Tracking Switch Access Solution for Clients with Severe and Multiple Disabilities

Masters Thesis

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Declaration

I certify that this work does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signature: Leonie Rich-Perrett

Date: 16/10/2017

Table of Contents

DECLARATION **1**

TABLE OF TABLES **6**

GLOSSARY **7**

ABSTRACT **8**

ACKNOWLEDGEMENTS **9**

1. INTRODUCTION **10**

1.1. Background 10
1.1.1. Disability in Australia 10
1.1.2. Technologies that Enable Access 11
1.2. Project Motivation 15
1.3. Current Situation 16
1.4. Knowledge Gap 29
1.5. Project Aims and Objectives 29
1.6. Design Requirements 30
1.7. Project Value 30
1.8. Previous Work 31
1.9. Methodology 35
1.10. Thesis Structure 36

2. LITERATURE REVIEW **37**

2.1. Mouse Cursor Control Methods for Computer Access 37
2.2. Binary Switch Input Methods for Control of User Interfaces 43
2.3. Summary 48

3. SYSTEM DESIGN AND DEVELOPMENT **50**

3.1. Hardware 50
3.1.1. Intel RealSense SR300 50
3.1.2. Intel RealSense SR300 Properties (Intel, 2016a) 52
3.1.3. Intel RealSense SR300 Camera Requirements (Intel, 2016a). 52
3.1.4. Suitable Tablets/Laptops 52
3.2. Software 56
3.2.1. Improvements from 'Proof of Concept' Prototype 56
3.2.2. FaceTracker GUI 59

4. METHODOLOGY **68**

4.1. NSASA 69
4.2. Questionnaire 70
4.3. Access Technology Expert Trial Method 71
4.4. Clients Trial Method 72

5. RESULTS AND DISCUSSION **74**

5.1. Access Technology Experts – Utility Questionnaire Results - Part #1 74
5.1.1. Mouth Open Expression 74

5.1.2. EYEBROW RAISE EXPRESSION 76
5.1.3. PUFF CHEEK EXPRESSION 77
5.1.4. TONGUE OUT EXPRESSION 78
5.1.5. SMILE EXPRESSION 79
5.1.6. KISS EXPRESSION 80
5.2. ACCESS TECHNOLOGY EXPERTS – UTILITY QUESTIONNAIRE RESULTS - PART #2 80
5.2.1. SUMMARY 82
5.3. CLIENT RESULTS - OVERVIEW 83
5.3.1. NSASA RESULTS 83
5.4. CLIENT CASE #1 – EK 86
5.4.1. COMPARISON BETWEEN CURRENT AND DEVELOPED SYSTEM (NSASA RESULTS) 87
5.4.2. QUESTIONNAIRE FEEDBACK 88
5.4.3. SUMMARY 89
5.5. CLIENT CASE #2 – RE 90
5.5.1. COMPARISON BETWEEN CURRENT AND DEVELOPED SYSTEM (NSASA RESULTS) 91
5.5.2. QUESTIONNAIRE FEEDBACK 92
5.5.3. SUMMARY 94
5.6. CLIENT CASE #3 – JA 94
5.6.1. COMPARISON BETWEEN CURRENT AND DEVELOPED SYSTEM (NSASA RESULTS) 95
5.6.2. QUESTIONNAIRE FEEDBACK 96
5.6.3. SUMMARY 98
5.7. CLIENT CASE #4 – CH 98
5.8. POST-TESTING IMPROVEMENTS - INTEGRATION WITH GRID 3 100
5.8.1. ACCESS THROUGH GRID 3 FOR USERS 100
5.8.2. DOCKING 101
5.9. POST-TESTING IMPROVEMENTS - APPLICATION DESIGN 105
5.9.1. FACE LOST ERROR 105
5.9.2. PAUSING OF SYSTEM 106
5.9.3. ADDITION OF BLINK EXPRESSION 107
5.10. POST-TESTING ANALYSIS - EFFECT OF VARIOUS LIGHTING CONDITIONS ON TRACKING 107
5.10.1. NORMAL LIGHT 108
5.10.2. LOW LIGHT 108
5.10.3. BRIGHT LIGHT/ REFLECTIVE SURFACE 109
5.10.4. SUNLIGHT FROM WINDOW 110
5.10.5. SUNLIGHT OUTDOORS 111
5.10.6. LYING IN BED 112
5.11. POST-TESTING ANALYSIS - SYSTEM USE WITH OTHER COMPUTER ACCESS METHODS 114

6. CONCLUSIONS 116

6.1. SIGNIFICANCE OF RESEARCH 117
6.2. LIMITATIONS OF RESEARCH 117
6.3. FUTURE WORK 118

7. APPENDICES 122

7.1. APPENDIX A – FACETRACKER CODE SAMPLE 122
7.2. APPENDIX B - ETHICS APPROVAL LETTER, INFORMATION SHEET AND CONSENT FORM 125
7.3. APPENDIX C - NSASA RAW DATA 132
7.4. APPENDIX D – QUESTIONNAIRE 133

8. REFERENCES 135

Table of Figures

Figure 1: Level of activity limitations within Australian population 2015 (ABS 2016). 10
Figure 2: Flow diagram of access technology design (Tai et al., 2008)... 11
Figure 3: Dwell Clicker 2 - mouse button replicator software. 12
Figure 4: Grid 3 single switch scanning - row selection. 13
Figure 5: Grid 3 single switch scanning - cell selection.. 13
Figure 6: Grid 3 double switch scanning - first press of switch 1 (advance). 14
Figure 7: Grid 3 double switch scanning - second press of switch 1 (advance)... 14
Figure 8: EK trialling Intel RealSense camera at MMRF lab at Flinders University.. 32
Figure 9: Proof-of-concept prototype application – video stream (window #1). 32
Figure 10: Proof-of-concept prototype application – errors update (window #2). 33
Figure 11: Flowchart of proof-of-concept prototype application developed during WIL placement in 2016........... 34
Figure 12: Self-testing of developed prototype system. 35
Figure 13: Two year old with cerebral palsy using CameraMouse (Betke et al., 2002)... 38
Figure 14: Magic Key system set-up to track user’s nostril movement (Fejtová et al., 2009). 41
Figure 15: EyeKeys access solution set-up to detect users eye movement (Magee et al., 2008). 42
Figure 16: Access solution ‘14Control’ which monitors users eye movement (Fejtová et al., 2009). 42
Figure 17: Set-up of multi-camera tongue protrusion switch application (Leung, 2010). 44
Figure 18: Setup of thermal camera trial (Memarian et al., 2011). 45
Figure 19: Throat vibration access solution system (Chan et al.,2010)... 47
Figure 20: Intel® RealSense™ SR300 camera (Intel, 2017a). 50
Figure 21: Intel RealSense SR300 3D imaging system (Intel, 2016a). 51
Figure 22: Intel RealSense SR300 depth stream data flow (Intel, 2016a). 51
Figure 23: VJoy Monitor – shows activated (red) and inactivated buttons (grey) (Eizikovich, 2016b). 56
Figure 24: Flow Chart of updated video window code design. 58
Figure 25: Home page of FaceTracker application GUI. 59
Figure 26: Select user profile window of FaceTracker application. 60
Figure 27: Add user pop-up window 60
Figure 28: Settings window of FaceTracker application. 61
Figure 29: Test window of FaceTracker application.. 62
Figure 30: SQLite database - tables utilised in FaceTracker application. 63
Figure 31: Taskbar icon and context menu - showing the selection of the pause camera function. 64
Figure 32: Video window user feedback - switch activation for mouth open expression. 65
Figure 33: Video window user feedback - switch activation for tongue out expression. 65
Figure 34: Video window user feedback- face occluded error.. 66
Figure 35: Video window user feedback- face out of frame error. 67
Figure 36: Video window user feedback- face lost error 67
Figure 37: FaceTracker pilot trial protocol flow diagram. 68
Figure 38: Comparison of individual utility questionnaire results part 1 ratings (mouth open). 75
Figure 39: Comparison of mean values for all system performance areas (mouth open). 75
Figure 40: Comparison of individual Utility Questionnaire results part 1 ratings (eyebrow raise). 76
Figure 41: Comparison of mean values for all system performance areas (eyebrow raise)...................................... 76

Figure 42: Comparison of individual Utility Questionnaire results part 1 ratings (puff cheek). 77
Figure 43: Comparison of mean values for all system performance areas (puff cheek). 77
Figure 44: Comparison of individual Utility Questionnaire results part 1 ratings (tongue out). 78
Figure 45: Comparison of mean values for all system performance areas (tongue out). 78
Figure 46: Comparison of individual Utility Questionnaire results part 1 ratings (smile) 79
Figure 47: Comparison of mean values for all system performance areas (smile) 79
Figure 48: Comparison of individual Utility Questionnaire results part 1 ratings (kiss). 80
Figure 49: Comparison of overall NSASA scores for all end-users. 84
Figure 50: Comparison of NSASA individual motor, visual and process scores for all end-users. 84
Figure 51: Comparison of NSASA motor skill areas for all end-users. 85
Figure 52: Part 1 Utility Questionnaire results for all end-user trials. 85
Figure 53: Utility Questionnaire Part 1 - system performance areas mean comparison. 86
Figure 54: Client EK testing the developed FaceTracker computer access system. 87
Figure 55: Motor skill performance scores for client EK. 88
Figure 56: Utility Questionnaire Part 1 individual results for client EK. 88
Figure 57: Client RE using her current switch access method - single mechanical switch. 91
Figure 58: Motor skill performance scores for client RE. 92
Figure 59: Client RE using the FaceTracker system during the trial. 92
Figure 60: Utility Questionnaire Part 1 individual results for client RE. 93
Figure 61: JA using current switch access method. 95
Figure 62: Motor skill performance scores for Client JA. 96
Figure 63: JA using FaceTracker system during trial - mouth open expression. 96
Figure 64: Utility Questionnaire Part 1 individual results for client JA. 97
Figure 65: Client CH using her current single switch method for computer access (candy corn switch). 99
Figure 66: FaceTracker system mounted above bed during trial - showing 'face out of frame' error. 99
Figure 67: Customised Grid 3 computer access grid for access to FaceTracker grid. 100
Figure 68: Customised Grid 3 FaceTracker grid for access to FaceTracker application. 100
Figure 69: Newly designed FaceTracker feedback widget - showing video display. 101
Figure 70: Newly designed FaceTracker feedback widget - showing non-video display. 102
Figure 71: Adjusted application design - home window. 103
Figure 72: Adjusted application design - new user window. 103
Figure 73: Adjusted application design - settings window. 104
Figure 74: Adjusted application design - settings test window. 104
Figure 75: Feedback display widget showing orange border for 'face lost' error. 105
Figure 76: Feedback display widget showing red border for 'face out of frame' error. 105
Figure 77: Feedback display widget showing red border for 'face occluded' error. 106
Figure 78: Feedback display widget showing paused camera via taskbar icon menu. 106
Figure 79: Grid 3 FaceTracker set showing paused system via red highlighted cell. 107
Figure 80: Testing of FaceTracker in normal indoor lighting conditions. 108
Figure 81: Testing of FaceTracker in low indoor lighting conditions. 109
Figure 82: Testing of FaceTracker in bright lighting conditions with reflective surface. 110
Figure 83: Testing of FaceTracker in sunlight from window lighting conditions- direct light. 110
Figure 84: Testing of FaceTracker in sunlight from window lighting conditions - from left side. 111
Figure 85: Testing of FaceTracker in sunlight from window lighting conditions – from right side. 111
Figure 86: Testing of FaceTracker in outdoor lighting conditions. 111
Figure 87: Testing of FaceTracker in bed (white pillow) – low lighting conditions. 112
Figure 88: Testing of FaceTracker in bed (grey pillow) - low lighting conditions. 112

FIGURE 89: TESTING OF FACETRACKER IN BED (BLACK PILLOW) – SUNLIGHT FROM WINDOW LIGHTING CONDITIONS. 112
FIGURE 90: TESTING OF FACETRACKER IN BED (WHITE PILLOW) – SUNLIGHT FROM WINDOW LIGHTING CONDITIONS. 113
FIGURE 91: TESTING OF FACETRACKER WITH MECHANICAL SWITCH. 114
FIGURE 92: TESTING OF FACETRACKER WITH QUHA ZONO MOUSE POINTER DEVICE. 115

Table of Tables

TABLE 1: COMMERCIALLY AVAILABLE DIRECT ACCESS TECHNOLOGIES. 18
TABLE 2: COMMERCIALLY AVAILABLE INDIRECT ACCESS TECHNOLOGIES. 25
TABLE 3: SPECIFICATIONS OF COMMERCIALLY AVAILABLE AAC DEVICES WITH USB 3.0. 53
TABLE 4: COMPARISON OF MICROSOFT SURFACE PRO 3 AND SURFACE PRO 4 SPECIFICATIONS. 54
TABLE 5: COMPARISON OF COMMERCIALLY AVAILABLE 2-IN-1 DEVICES WITH A USB 3.0 PORT. 55
TABLE 6: ACCESS TECHNOLOGY EXPERTS UTILITY QUESTIONNAIRE PART 2 RESULTS QUALITATIVE FEEDBACK - QUESTION 1 81
TABLE 7: ACCESS TECHNOLOGY EXPERTS UTILITY QUESTIONNAIRE PART 2 RESULTS QUALITATIVE FEEDBACK - QUESTION 2 81
TABLE 8: ACCESS TECHNOLOGY EXPERTS UTILITY QUESTIONNAIRE PART 1 RESULTS QUALITATIVE FEEDBACK - QUESTION 3 81

Glossary

AAC – Augmentative and Alternative Communication

BCI - Brain-Computer Interface

Dysarthria – muscles used for speech are weak and difficult to control, therefore often resulting in slurred or slow speech

Dysphagia – difficulty swallowing

Dystonic behaviour - involuntary muscular spasms and abnormal posture due to abnormal muscle tone

ECU – Environmental control unit

GMFCS – Gross Motor Function Classification System

GUI – Graphical User Interface

MACS - Manual Ability Classification System

OT - Occupational Therapist

POV- Point of View

PUI- Perceptual user interface

RAM – Random- access memory

SDK – Software development kit

Strabismus – condition where eyes point in different directions

WIL – Work- integrated learning placement

WPF - Windows presentation foundation

XAML – Extensible Application Mark-up Language

Abstract

The aim of this research project is to design, develop and trial a new computer access switching method consisting of an application which creates an interface between an Intel RealSense SR300 3D camera and switch scanning software such as Sensory Software's Grid 3. The system will allow for a purposeful facial expression movement (e.g. mouth open) produced by the user to be detected as a switch press.

The reason for undertaking this project is to provide a potential alternative for clients with severe and multiple disabilities who have limitations in their abilities to use other access technologies for communication, computer access and/or environmental control. In particular, it was designed to meet the needs of a client who has severe dystonic movement of his head and neck and therefore has been unsuccessful in finding an effective access method.

This thesis will continue work from a proof-of-concept application developed during the author's work-integrated learning (WIL) placement with industry partner Novita Children's Services (Novita) in 2016. Improvements will be made by addressing issues such as lagging/freezing of the application and accidental switch activations caused by talking, smiling and laughing. The application will also be further developed to be more user friendly and additional expression choices will be added to make the system more inclusive to a wider range of people. Trials will be undertaken by six access technology experts and four Novita clients who represent potential end users. Observations and feedback from the pilot trial will be used to make further adjustments to the system and to make recommendations for future work on the system.

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1. Introduction

1.1. Background

1.1.1. Disability in Australia

In 2015 there were approximately 3.4 million people with a disability in Australia who were limited in their ability to conduct core daily activities such as communication, mobility and self-care (ABS, 2016). As shown in Figure 1, people with severe or profound limitations made up 40% of this population and had the greatest need for help with activities (ABS, 2016).

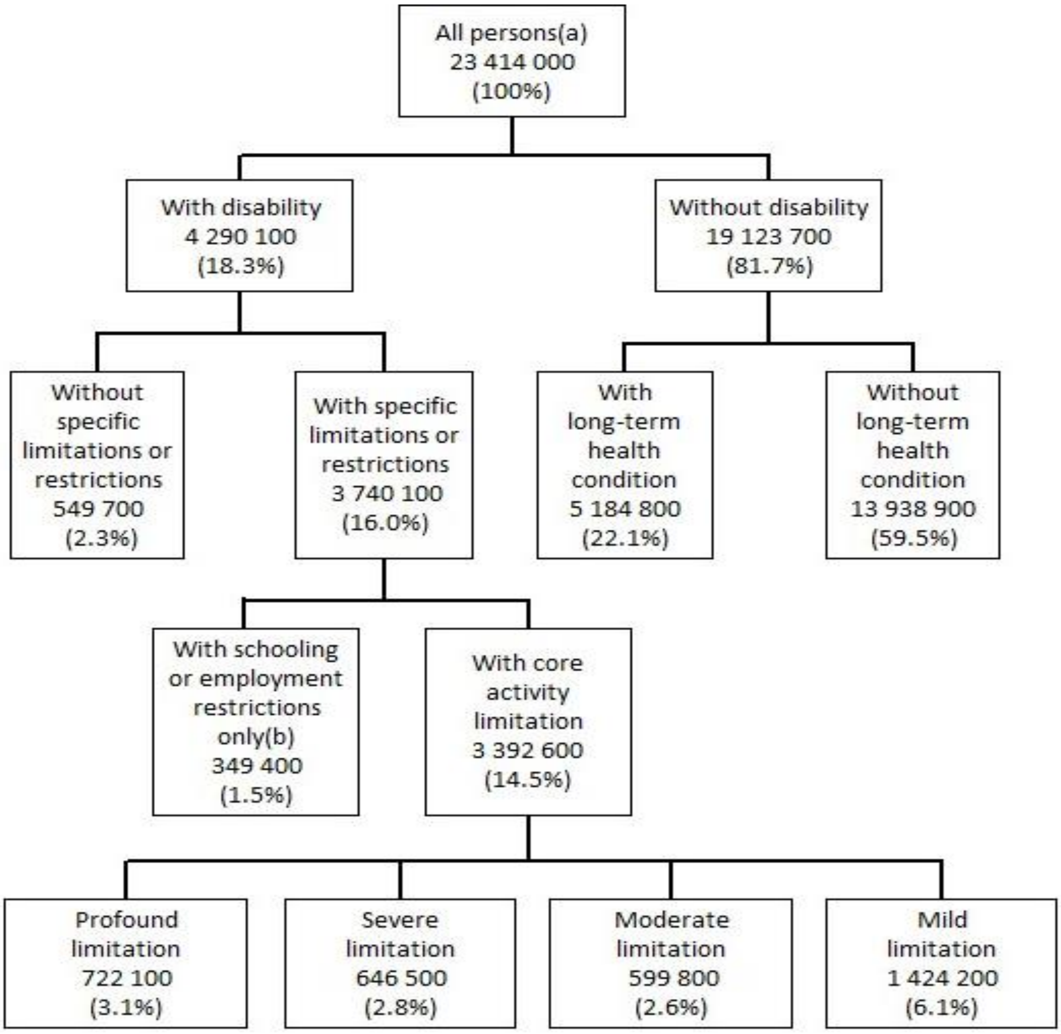

Figure 1: Level of activity limitations within Australian population 2015 (ABS 2016).

Communication is a large area in which assistance is sought, with 89.9% of people receiving help from their partner, parent or child on a regular basis and 43.5% also having help from a formal assistance service (ABS, 2016).

1.1.2. Technologies that Enable Access

Assistive technologies are *'any item, piece of equipment, product or system that is used to increase, maintain or improve the functional capabilities and independence of people with cognitive, physical or communication difficulties'* (ATiA 2017). A class of assistive technology known as access technologies are the focus of this thesis; the aim of their development is to increase independence in activities of communication, computer use and environmental control.

As shown in Figure 2, access technologies involve the use of an access pathway, that is an input method/device used to detect a functional intent (e.g. physical touch, camera or switch), as well as a signal processing component that analyses the input signal and determines the output signal required to provide the functional activity to be undertaken by the user interface (Tai et al., 2008).

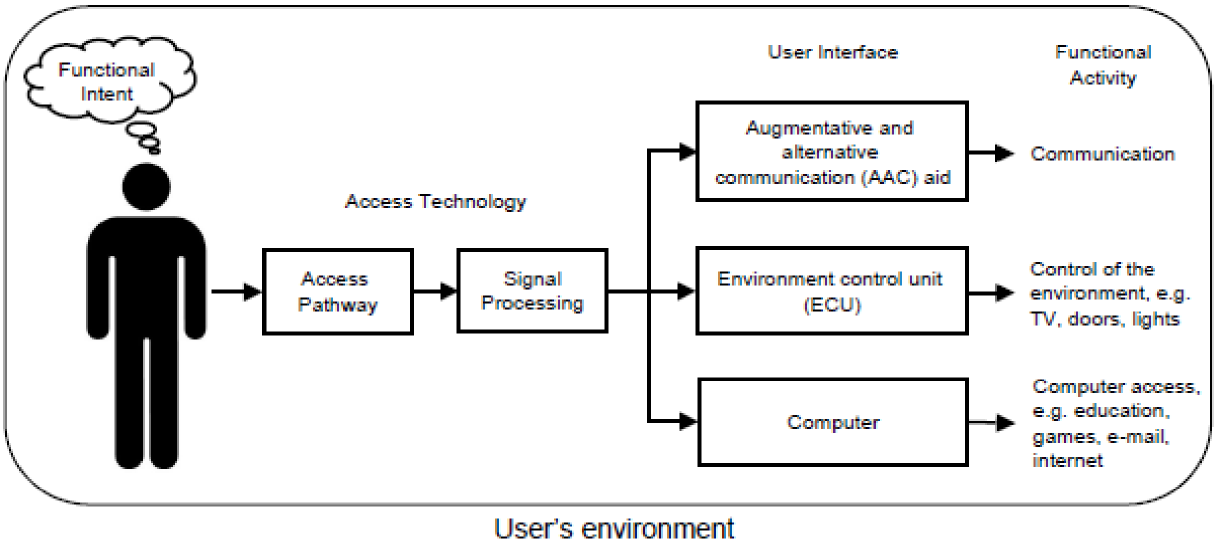

Figure 2: Flow diagram of access technology design (Tai et al., 2008).

There are two main types of input methods to access technologies, these are the direct and indirect methods. Direct access is the preferred method of access and includes access via physical touch as well as through common devices such as keyboards, mice and joysticks. Although this method offers higher speed and efficiency, direct access also requires the user to have a high level of motor ability to complete tasks without a high level of error (Brown et al., 2009).

For those with low or deteriorating fine motor skills, modified versions of these direct access devices may be used including keyboards with larger keys and/or keyguards (to prevent multiple key presses), or touch screen devices (RockyBay, 2010). Modified mice/joysticks include trackball devices and those that can be controlled with an alternate body part such as the mouth or foot. Additionally, for users with better ability to control their head and/or facial movement as opposed to their limbs there are also alternate mouse options such as eye-gaze systems or infrared head/face tracking systems (RockyBay, 2010). These systems often have a dwell feature or may require an additional switch or program such as 'Dwell Clicker 2' shown in Figure 3 to activate a mouse click when the cursor is rested on a button (left, right, double or drag).

Figure 3: Dwell Clicker 2 - mouse button replicator software.

Indirect access methods have lower motor demands placed on the user but often have a much higher cognitive demand, the most common type is switch scanning (Brown et al., 2009). Sensory Software's 'Grid 3' is a commonly used switch scanning software that will be utilised in this project. The software can be personalised to perform functions based on the user's abilities and needs. Switch scanning may be undertaken by one or two switches and may be set to have visual (highlighted cells) and/or audio (descriptions of cells read aloud) feedback (Brown et al., 2009). Furthermore, scanning may be performed in a variety of ways:

1. Sequentially: scan through each cell one after the other.
2. Row-column: scan each row, and then each column in selected row.
3. Block: scan through blocks of cells, and then through each cell of selected block.
4. Inverse: user holds down switch to perform one of the scanning methods above (1-3) and releases to make selection.

In single-switch scanning (set to row-column scanning method) the software automatically scans firstly through the rows on the screen, with a bar to help with timing and selection as shown in Figure 4.

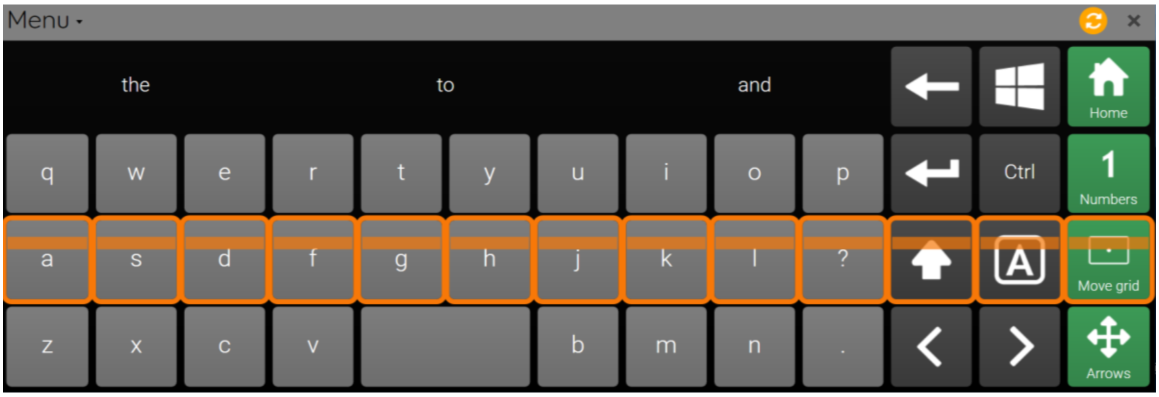

Figure 4: Grid 3 single switch scanning - row selection.

Once the row containing the users desired letter/cell is highlighted, the user must activate their switch to select it (RockyBay, 2010). Following this, the software will begin to scan through the columns of the selected row as shown in Figure 5. The user waits until their desired cell is highlighted and activates their switch again to select and perform its set function (e.g. type letter, backspace, move mouse etc.).

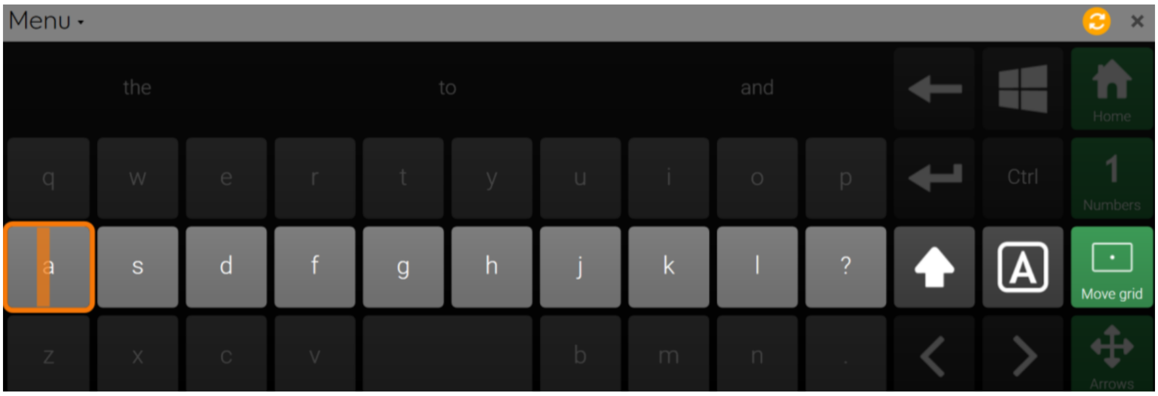

Figure 5: Grid 3 single switch scanning - cell selection.

This method requires less switch presses and therefore can be less fatiguing than double switch scanning (see below). The rate of automatic scanning can also be increased or decreased depending on the user's abilities. However, if the user does not possess good timing skills they could become frustrated with the amount of times it takes for the system to rescan through all the options to undo any mistakes made and reach their desired selection.

Two-switch scanning requires two individual switches and allows the user to scan through the selections at their own pace with the first switch (advancement shown in Figure 6 and 7) and then make their selection with the second switch.

Figure 6: Grid 3 double switch scanning - first press of switch 1 (advance).

Figure 7: Grid 3 double switch scanning - second press of switch 1 (advance).

Two-switch scanning means that the user must press the switch a significant number of times more than the single-switch scanning method. However, it is less likely that they will miss their desired selection due to poor timing skills or lack of focus and it is less cognitively demanding (RockyBay, 2010).

The indirect access method is the best method for those who are limited in their physical abilities, although it takes longer it still provides them with the ability to independently communicate, access their computer and environment (RockyBay, 2010). Switches may come in two forms – contact and non-contact. Contact switches include jellybean, string, plate, sip and puff and squeeze switches. Non-contact switches include infrared eye-blink switches and sound-activated switches (Brown et al., 2009).

1.2. Project Motivation

The motivation behind this project is a 15-year-old Novita client with mixed dyskinetic cerebral palsy, who will be referred to as EK, whose ability to access his computer to communicate and control his environment are severely limited due to his condition. EK's gross motor function has been categorised to be level V using an assessment tool called the 'Gross Motor Function Classification System (GMFCS)'. This means that he *is 'transported in a manual wheelchair in all settings'* and has limitations in his '*ability to maintain antigravity head and trunk postures and control leg and arm movements'* (Cerebral-Palsy-Alliance, 2017a). In addition to this, he has also been categorised as level V using the 'Manual Ability Classification System (MACS)' assessment tool. This means that he is not able to handle objects or complete simple actions with his hands (Cerebral-Palsy-Alliance, 2017b).

Since early childhood, the client has trialled many different methods of access to assistive technology with his occupational therapist in his therapy intervention sessions, none of which were very successful. These have included: mechanical switches with trials of activation via a wide range of body parts (e.g. head, arm, hands, knee, foot), an infra-red eye blink switch, a 'Sip n Puff' switch, eye gaze technology, the Brain-Computer Interface (BCI) 'Brain-Fingers' and voice recognition software.

Wearable technologies such as the BCI technology, infra-red eye blink systems and systems that require close positioning to the body such as sip and puff systems and mechanical switches, have proven to be unsuitable due to risk of injury due to EK's involuntary dystonic movements of his body. It is also difficult to keep these systems in an appropriate position for operation, for example systems requiring headbands are dislodged when contacting the wheelchair headrest constantly with regular head movement. Eye gaze technology is unsuccessful due to EK not having the ability to keep his head in a stable position within the tolerance limits of the camera. Dysphagia and dysarthria affect his ability to be recognised by voice recognition software. Lag in responsiveness of currently available commercial BCI technologies currently also have meant that these options do not give the control needed for effective timed switch scanning access to his Grid 3 software.

EK does not have an intellectual disability and is currently studying at year 9 level in a mainstream school. Currently he is using a sound switch, activated by the word ‘now’ in conjunction with switch scanning software as his means of computer access and environmental control. Unfortunately, this method of access has a major functional limitation due to it being “noisy” and therefore not always appropriate to use, particularly in a classroom environment and in the community. The system is also affected by external noise interference; often producing accidental switch activations in noisy environments, even when only operated in the home environment. EK’s dysarthria means that the timed speech output required to activate his sound switch is very effortful, resulting in a large amount of dystonic movement, sweating and fatigue after a short period of time.

EK’s mother and his occupational therapist identified that his highest level of control is with his mouth/tongue. It is hoped that through this project a more proficient, non-wearable access method can be found in order to provide EK with a more socially acceptable, less fatiguing, more efficient and reliable access method that he can use to give him access to computers, environmental control and potentially into the future, powered mobility.

1.3. Current Situation

Access technologies have provided many people with mild to moderate activity limitations with a new sense of life; by improving their ability to communicate and interact with other people and their environment at home, as well as in both the community and workplace. Significant advances in technology and medicine in recent years has resulted in an increasing amount of people living longer than before, including those with disabilities. Access technologies work well for those with single, mild-moderate limitations as they can easily fit the specific target disability that many devices are designed. However, those with severe, profound or multiple limitations, such as EK, are more likely to have their need for help with activities only partially met or not met at all by these devices. 48.2% of people less than 65 years of age and 37.4% of those greater than 65 years reported this to be the case (ABS 2016).

The predominant resource for Australian occupational therapists providing access solutions to their clients is through assistive technology suppliers including Spectronics, Zyteq, Communicate AT and Technical Solutions. Available products on these supplier's websites, in addition to those listed on Assistive Technology Australia and Independent Living Centres Australia have been scanned and main categories of access to computers have been listed in Table 1 for direct access methods and Table 2 for indirect access methods. These tables give an overview of the current access methods available to clients, their approximate cost, limitations they cater for, whether they are suitable for clients with dystonic movements, as well as if they require contact for activation or any wearable components.

Table 1: Commercially available direct access technologies.

Access Method		Approximate cost (AUD)	Level of motor disability	Caters to dystonic movement?	Contact required?	Wearable Part?	Other Notes
Modified Keyboard 	Keyboards with larger keys, better visibility, spacing and/or keyguards. Examples include: • VisionBoard2 (pictured) • BigKeys LX	$100-$250	Tremor/ mild limitations in hand control	No	Yes	No	
Typing Aids 	Assists those who have difficulty pressing individual keys. Examples include: • Norco Typing Aid (pictured) • Slip-On Typing Aid	$24-$64		No	Yes	Yes	

Access Method		Approximate cost (AUD)	Level of motor disability	Caters to dystonic movement?	Contact required?	Wearable Part?	Other Notes
Modified Mouse- Trackpad 	Controls speed and direction of mouse without moving hand/wrist, only soft touch required. Example: • Orbitrack (pictured)	$493	Limit in ability to apply hand force.	No	Yes	No	
Modified Mouse- Trackball 	Rollerball for mouse movement with two buttons above for non-accidental mouse press. Examples include: • BIGtrack (pictured) • n-ABLER Trackball	$150-$573	Tremor/ mild limitations in hand control	No	Yes	No	• Can also attach external switches for mouse clicks.

Access Method		Approximate cost (AUD)	Level of motor disability	Caters to dystonic movement?	Contact required?	Wearable Part?	Other Notes
Mouth-Operated Joysticks 	Allows for mouse movement through mouth piece movement – clicks through sip and puff combinations. Examples include: • Lifetool IntegraMouse Plus (pictured) • QuadStick • Quadjoy	$506 - $3020	Inability to use hands to control computer	No	Yes	No	
Foot Mouse 	Slipper and/or pedals used to control mouse cursor movement and mouse clicking options. Examples include: • Boomer Foot Mouse • Bili Mouse Foot Slipper (pictured)	$216 - $900		No	Yes	Depending on device – some require slipper, others just buttons.	

Access Method		Approximate cost (AUD)	Level of motor disability	Caters to dystonic movement?	Contact required?	Wearable Part?	Other Notes
Voice Activated Keyboard/Mouse	Use voice commands to control computer mouse and type words without keyboard. Example: Dragon NaturallySpeaking 13	N/A	Inability to use hands for access but good speech	Yes	No	No	
Hands-free Infrared Mouse cursor 	Tracks a small reflective dot (or dots) through IR sensor which user places on their face, glasses or hat - mouse cursor will then replicate head movement. Examples include: TrackerPro (pictured), HeadMouse Nano, SmartNav 4 AT and Natural Point TrackIR 5 Pro	$190- $1630	Those with limited hand motor control but relatively good head / face motor control	No	No	Yes, but only small sticker.	• Plug and Play. • Not affected by sunlight. • Needs external switches or software for mouse clicks.

Access Method		Approximate cost (AUD)	Level of motor disability	Caters to dystonic movement?	Contact required?	Wearable Part?	Other Notes
Gyroscopic Air Mouse 	Small mouse device which can attach to headband, glasses, cap etc. and usb connects to device to computer via wireless radiolink up to 10m Example: Quha Zono	$1463 + wearable accessories	Those with limited hand motor control but relatively good head / face motor control.	No	No	Yes	• Option of add on puff switch for clicking.
CameraMouse 	User choses a distinct point on their face (e.g. nose, eyebrows, glasses frame) for the software to track. Has option to dwell for mouse click.	Free		No	No	No	• Not very accurate. • Only requires webcam.

Access Method		Approximate cost (AUD)	Level of motor disability	Caters to dystonic movement?	Contact required?	Wearable Part?	Other Notes
Smyle Mouse 	Software package requiring only webcam to run. Tracks head movement and mouse clicks can be achieved by smile expression or by dwelling.	$632	Those with limited hand motor control but relatively good head / face motor control.	No	No	No	• Can be used anywhere, indoors or outdoors. • Advertises use of other expressions but options not listed.
GlassOuse Mouse Emulator 	Infrared transmitter embedded into glasses to translate head movement into mouse movement and a 'bite click' for mouse click action.	$399		No	Yes, lips or teeth to conduct mouse click.	Yes	• No external software or hardware required for mouse click. • Headband is obvious and may be un-comfortable.

Access Method		Approximate cost (AUD)	Level of motor disability	Caters to dystonic movement?	Contact required?	Wearable Part?	Other Notes
Brain- Computer Interface  BrainFingers	Electrical signals from brain, face muscle movements and eye movements are detected by sensors in headband and software converts this into simple left mouse click, cursor control or keyboard key presses.	$2200	In-ability to control limbs for computer access. Good cognitive ability.	Yes	No	Yes, headband.	• Interference from movement of muscles • Lagging system.
Eyegaze Systems  Examples include: Eyetech TM5 Mini (pictured), Tobii Dynavox PCEye Mini, Intelligaze 360 Eye Gaze and NuEye Eye Gaze.	Translates eye movement into mouse cursor movement. User focuses on section of screen to move cursor to that point. Dwell feature or additional switch can be used for mouse click.	$2395 - $8995 (for separate device not including tablet or AAC device)	Limited hand control but relatively good head / face control and good cognitive ability.	Yes	No	No	• Requires large amount of cognitive focus.

Table 2: Commercially available indirect access technologies.

Access Method		Approximate cost (AUD)	Level of motor disability	Caters to dystonic movement?	Contact required?	Wearable Part?	Other Notes
Mechanical switches 	Force applied to surface to activate switch - provides tactile and auditory feedback to user. Examples include: • Able net String Switch • JellyBean Twist (pictured) • Orby Switch • Chin Switch • Ultimate Switch • FingerButton 30 • Flex Switch • Foot Switch	$80 - $415	Able to control limbs relatively well, but reduced fine motor function	No	Yes	No	
Touch Switches 	Only light touch of surface required to activate switch Examples include: • Plate Switch (pictured) • Lolly Switch	$136- $140	Inability to produce force for mechanic switch.	No	Yes	No	

Access Method		Approximate cost (AUD)	Level of motor disability	Caters to dystonic movement?	Contact required?	Wearable Part?	Other Notes
Proximity Switch 	Requiring no force – activates when skin is within 10mm of surface. Examples include: • Candy Corn (pictured) • Mini-Beamer Wireless • Wave Switch	$290-$400	Inability to produce force or proper contact for mechanic/ touch switch.	No	No	No	
Tilt Sensor Switch 	Can be attached to head, arm or leg. Switch activated by altering angle of device. Example: Tilt Switch (pictured)	$110	Those with limited hand motor control but relatively good head / face motor control and good cognitive ability.	No	No	Yes	
Muscle Movement Sensor Switch 	Sensor can be activated by small eyebrow, jaw or other muscle movement. Piezo may also activated by change in temperature (breath or touch). Examples include: • Piezo Switch Kit (pictured) • Twitch Switch	$203- $515		No	Only if using touch to activate.	Yes	• Wires create an obvious and potentially uncomfortable access device.

Access Method		Approximate cost (AUD)	Level of motor disability	Caters to dystonic movement?	Contact required?	Wearable Part?	Other Notes
Eye-Blink Sensor 	Can detect purposeful blink from natural blinking action. Device can be put in fiber optic mode to detect other body part movements. Example: • [Fibre-Optic Eye Blink Switch]	$1092.50	Eye blink only access control point.	No	No	Yes, Head strap	Works best when eye blink is the only action able to be performed by user.
Infrared Sensor Switch 	Infrared Sensor can detect, blink, eyebrow, finger, head, facial muscle movement to activate switch. Example: • [SCATIR Switch]	$1140	Ability to control face /head movement.	No	No - Distance from user can be calibrated.	No	• Can be mounted on glasses, or gooseneck mount.
Squeeze Switch 	Changes in air pressure-trigger switch activation. Can adjust sensitivity. Examples: • [Balloon Switch] (pictured) • [Squeeze Switch]	$175-$195	Reduced fine motor control but ability to provide squeeze hand movement.	No	Yes	No	

Access Method		Approximate cost (AUD)	Level of motor disability	Caters to dystonic movement?	Contact required?	Wearable Part?	Other Notes
Pneumatic Switch 	Turns sip and puffs of air into electrical signals which can be used as switch input. Examples: • Origin Instruments Sip/Puff Switch (pictured) • Sip Puff Switch	$448	Inability to use limbs for computer access but good control of head/neck/ airflow.	Somewhat but not large movement as could be dangerous.	Yes	Yes	
Sound Switch 	Switch activated by human voice – sensitivity can be adjusted to suit client needs. Example: • Sound Switch Pro (pictured)	$248	Those who are limited in motor control but can produce audible tone.	Yes	No	No	• Can't be used in all environments – noisy • Switch can be triggered by external noise. • EK's current switch.
EMG Muscle Movement 	Sensor is placed over skin on muscle of choice for switch activation. Electrical signals detected on contraction of muscle activates switch. Example: • NeuroNode EMG Switch (pictured)	$10,000 +	Good control of muscle sensor is placed on.	No	Yes	Yes	• Potential interference from other body part muscle movements.

1.4. Knowledge Gap

Prescribing technology for a person with severe and multiple activity limitations can be a challenge for occupational therapists (OT's), particularly because there is minimal research which compares the effectiveness of different access technologies and their success with varying client profiles (Alves et al., 2010).

Often the systems which are prescribed do not offer optimal outcomes; reliability or efficacy may be low or users may not be able to use the device for long periods of time due to fatigue. Other potential disadvantages of current commercially-available systems for those with complex needs include difficulty of use, high-cost or the obviousness of devices which are noisy or have wearable components (Huo, 2011, Loewenich and Maire, 2007). In the past 20 years there has been a significant increase in research focusing on providing the same life improvements to people in society with severe disabilities as those with less-complex disabilities. This research into recently developed technologies is discussed further in the literature review in Chapter 2.

Currently there are no known commercially available technologies that provide sufficient access to technology for those with severe dystonic movement limitations, without significant disadvantages such as those mentioned above also being present.

1.5. Project Aims and Objectives

The aim of this project is to narrow the current knowledge gap by creating an alternative switch access solution that could potentially be used by people with severe or multiple disabilities, who have limitations in their abilities to use other access technologies for communication, computer access and/or environmental control.

The above aim will be achieved by fulfilling the following objectives:

- Undertaking an in-depth literature review to discover current research in the access technology field.
- Further developing the application from the work placement proof-of-concept prototype (details in section 1.8) - to not only improve upon its design and abilities but also enable the device to cater to a wider range of people in addition to the client who was the motivation behind the project.

- Learning how to create an application which is user-friendly; simple, easy to use and intuitive.
- Testing the device with field experts and end-users of the project for feedback.
- Analysing feedback for ideas on how to improve the design and determine if it is likely the device will be successful on the market.
- Begin to implement feedback into version 2 of application and recommend future work to be undertaken.

1.6. Design Requirements

To fill the knowledge gap, it was determined that the device must meet the following criteria:

- Access method must limit interference to access from dystonic movement.
- Must be portable and useable with high level of accuracy at home and community environments (e.g. school) – no external interferences.
- Non-contact and no wearable components so that it can cater to severe disabilities without risk of injury.
- Should be an easy set-up solution that the user can predominantly use independently.
- Desirably low cost so that is affordable to as many people who need it as possible.

1.7. Project Value

The potential outcome of this study is that there will be a new access technology commercially available to be prescribed to clients with severe physical disabilities by their therapist. This will be particularly beneficial to those who are unable to reliably use alternative access methods to interact with technology but do have one or more reliable facial movements (mouth open/close, tongue out, kiss, cheek puff, eye brow raises, intentional blink etc.).

Likely users could include people with cerebral palsy (GMFCS V), motor neuron disease, spinal cord injury (quadriplegia with high level injury) or multiple sclerosis (late stage). Alternatively, users that do have a current switch access method may also benefit from this technology as it may increase their current accuracy and efficiency levels and/or provide a less painful or fatiguing access option. The software will be customisable as it directly interfaces with switch scanning software so that people with varying cognitive levels can benefit from it - from low level “cause and effect” access to high-level switch scanning capabilities.

It is important for those with severe and profound disabilities to have the same opportunities to interact with other people and participate in school, workplace and community activities through computer access, communication and environmental control. These opportunities allow for improvement in mental well-being and the ability to build social networks and support systems, as well as potentially enabling financial independence (ABS 2016).

1.8. Previous Work

Upon initial identification of the project by Annabelle Tilbrook through collaboration with David Hobbs in 2016, a brief literature review was undertaken by second year biomedical engineering students Thomas Beltrame, Anika Talukder and Clarence Chuah from Flinders University (Beltrame et al., 2016). Through their research they discovered that the Intel RealSense 3D Camera could be a potential access solution for EK due to its ability to track facial expressions and in particular his mouth movement.

The idea to develop a software system which harnessed the 3D cameras capabilities was then undertaken by the author as one of her Work Integrated Learning (WIL) Placement projects. EK was able to trial a sample face tracking program by Intel in the Multi-Modal Recording Facility (MMRF) lab at Flinders University as shown in Figure 8. This trial demonstrated proof of concept in the cameras tracking ability with EK’s dystonic movements for the project to be continued.

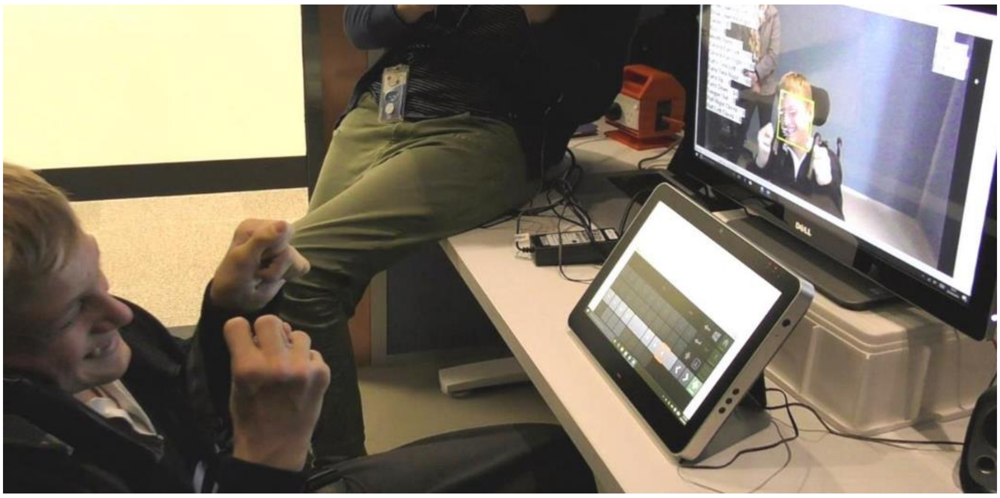

Figure 8: EK trialling Intel RealSense camera at MMRF lab at Flinders University.

A basic C++ ‘proof-of-concept’ application was developed through modification of Intel’s RealSense Software Development Kit (SDK) – ‘Face-tracking tutorial’ (Intel, 2016b). This application showed a video stream, with the identified face surrounded with a rectangle and landmarks identified with dots as shown in Figure 9. All tracking errors experienced were listed on an additional window as displayed in Figure 10.

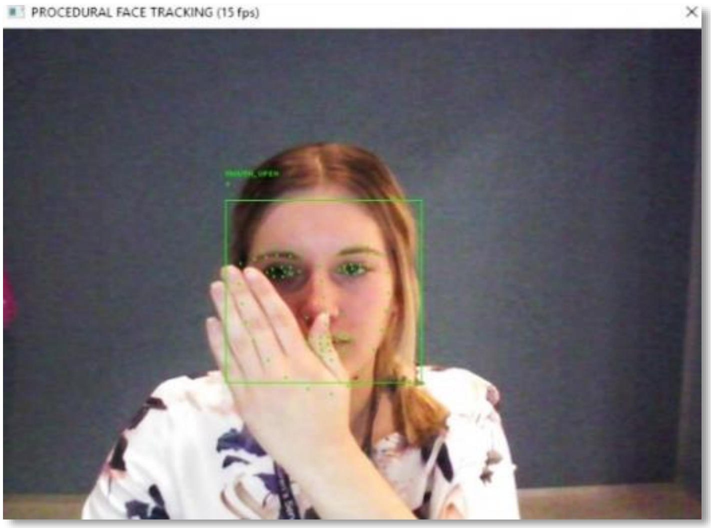

Figure 9: Proof-of-concept prototype application – video stream (window #1).

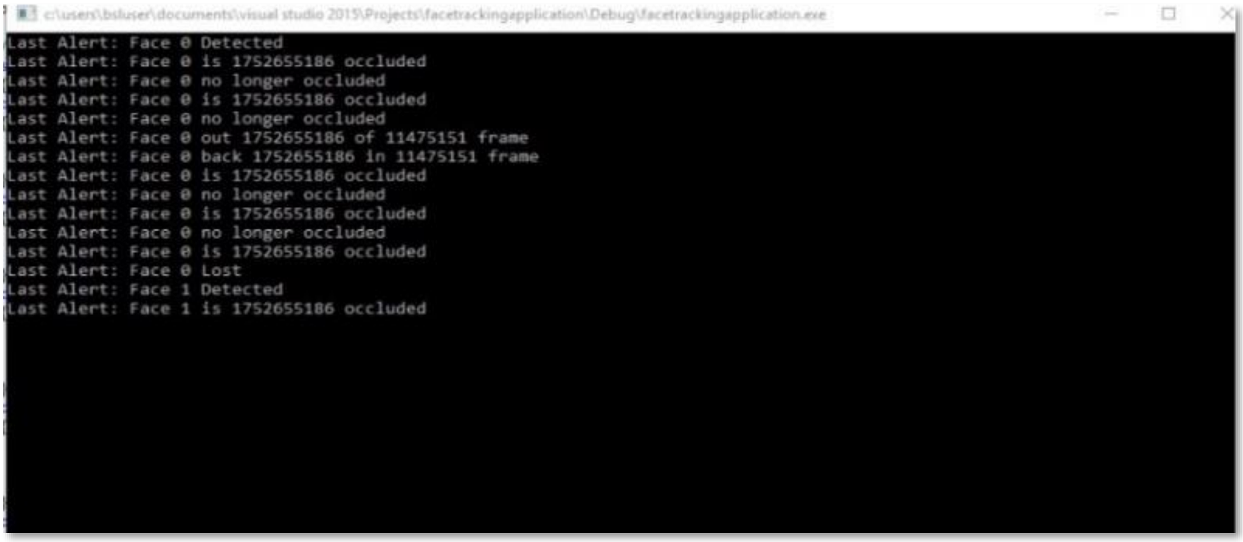

Figure 10: Proof-of-concept prototype application – errors update (window #2).

The application integrated the Intel RealSense SDK with the ‘vJoy’ virtual joystick device driver, so that when a mouth-open expression was detected by the Intel RealSense SR300 3D camera to be over a set threshold value (can be customised to be anywhere between 0 - 100), it was identified by the ‘Grid 3’ switch-scanning software as a ‘button press’. The basic application process is shown in the flow chart in Figure 11.

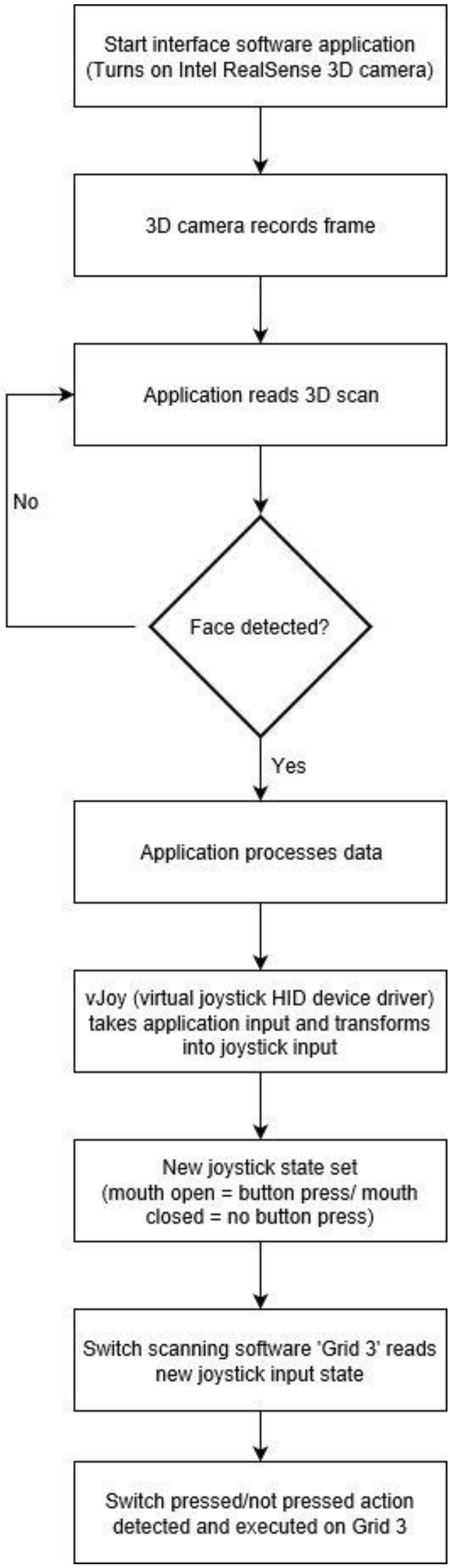

Figure 11: Flowchart of proof-of-concept prototype application developed during WIL placement in 2016.

The program was developed and self-tested as shown in Figure 12, to ensure it was working to the requirements of the project as described in section 1.6.

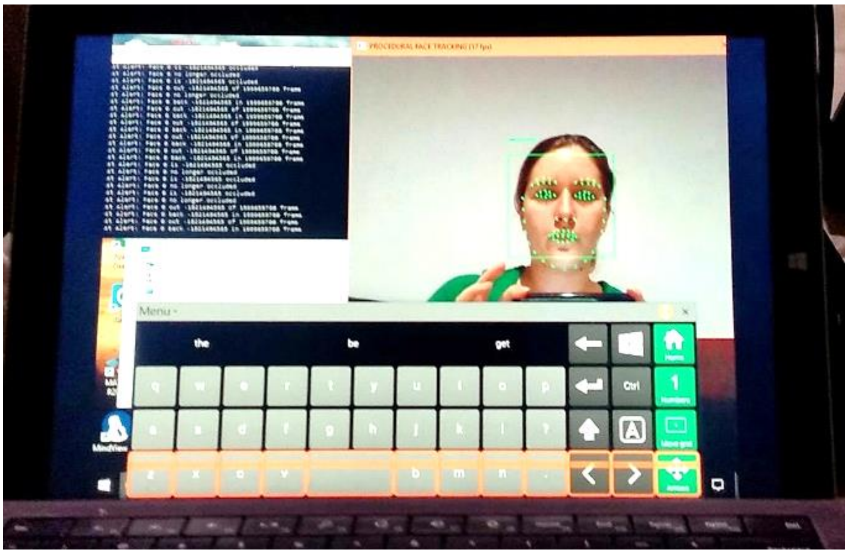

Figure 12: Self-testing of developed prototype system.

A proof-of-concept switch access prototype system was successfully developed that enabled the Intel RealSense SR300 3D camera to detect mouth open/close action to access and control the Grid 3 switch scanning software. However, the trials of the system with EK showed varying degree of success, with some issues which included:

- Lagging and/ or freezing of the system after large dystonic movements of head.
- Accidental presses occurring from talking/laughing.
- Application took up large area of screen and with Grid 3 software also running it was difficult for user to access what he wanted to and use application at the same time.
- Threshold setting (level of mouth open expression needed to activate switch) had to be manually adjusted by hard-coding the value when trying to find the appropriate level for EK.

1.9. Methodology

The aim of this thesis project is to firstly address the main functional issues that were encountered during the trials of the proof-of-concept prototype. Namely the freezing/ lagging of the application and accidental activations of the switch via open mouth expressions detected from smiling, laughing or talking during application use. Secondly, the graphical user interface (GUI) will be developed to be more user friendly and so that profiles can be set with specific thresholds and the ability to test the set threshold to find a suitable level for the user. Thirdly, further expression options will be added to the application such as ‘smile’, ‘tongue out’, ‘eyebrow raise’, ‘puff cheek’ and ‘kiss’. There will also be the option to choose two expressions for two-switch scanning. Finally, the prototype application will be tested by both experts in the field for beta testing of the application, as well as by a small number of potential end-users. This will provide direct feedback, so that improvements can be made to the application and it can be determined whether there is a potential for the system to be successful.

If trialled successfully, then the system will be a reliable, less effortful, non-contact, non-invasive and automatically calibrating system. It will be able to be personalised for each user, incorporate a variety of facial expression options and able to track dystonic movement of the head with minimal error. It will also be a no noise solution, which is also not susceptible to external noise interference and therefore able to be used in the school/community environment and not only in the home environment.

1.10. Thesis Structure

The structure of this thesis will begin with an overview of the current research in the field through a literature review in Chapter two. Chapter three will explain the design and development of the system, before an overview of the evaluation methods are given in chapter four, including reasons why these particular methods were chosen, and a layout of the testing procedures. Chapter five will deliver the results from the testing of the system, before the meaning of these results is discussed and post-testing changes to the application outlined in Chapter six. Finally, Chapter eight will summarise the outcomes of the project, the impact it has had on the assistive technology field and ideas/plans for further development.

2. Literature Review

Literature was searched for relevant articles that reported on a novel access technology suitable for people with severe or multiple disabilities, who have at least one site of reliable and repeatable motor control. Potential target groups for these types of technology include those with cerebral palsy, motor neuron disease, quadriplegia with high level injury, late stage multiple sclerosis, locked in syndrome or others with similar limitations who have difficulties with current technologies. A keyword search was conducted of databases which included: ProQuest, MEDLINE, PubMed, OneFile, SAGE Journals and Publications, Informa Healthcare Journals, Elsevier, Taylor & Francis Online-Journals, ScienceDirect Journals, PMC, IEEE Journals and Magazines, IEEE Conference Publications and BioMed Central. Google Scholar was also utilised as a search tool. Keywords used included: “assistive technology”, “access solution”, "access technology", “computer access", disability, rehabilitation and severe. Publication dates were limited between 1990 and 2017 and this search returned 307 peer-reviewed articles from the databases. These articles were screened by title and abstract and 35 articles with relevance were included in the following review. The articles have been split into the two predominate types of technology designs found in the literature, (1) alternative methods of mouse cursor control and (2) methods of activating a single-switch or button press for controlling a user interface.

2.1. Mouse Cursor Control Methods for Computer Access

Advances in computer technology has allowed for a new field of access technology research to emerge, involving the implementation of perceptual user interfaces (PUI’s) (Turk and Robertson, 2000). PUI’s allow for communication between computers and people through video streaming, in a very similar way to which humans would normally communicate with each other. Recent years have seen many advances in the development of computer algorithms that allow for real-time face, gesture and object tracking (Bradski, 1998, Gonzalez et al., 2010, González-Ortega et al., 2010, Jiang et al., 2016, Morris et al., 2002, Qian et al., 1998, Varona et al., 2008). These algorithms have subsequently been used to develop computer access methods for people with severe disabilities. One way in which video-based technology has been implemented is for control of a mouse cursor through facial feature detection. This is a potential computer access solution for people with severe disabilities who do not possess fine motor control skills of their limbs but are able to voluntarily move their head and neck to control the direction of a mouse feature accurately.

The CameraMouse (shown in Figure 13) is a prime example of a replacement mouse cursor option which has been designed to be nonintrusive, comfortable, easy to use, reliable, and an inexpensive communication device (Betke et al., 2002). The CameraMouse also allows for flexibility in the face/hand feature that is tracked. The nose, eyes, lips and thumb were all trialled as head movement tracking points. The nose was most successful due to it being easy to manoeuvre whilst enabling the eyes to remain focused on the screen and it is also the point on the face which remains most visible when the user rotates their head in varying directions. Both the nose and the mouth were found to be good points of tracking head movement due to the brightness contrast to surrounding features (Betke et al., 2002). It was suggested for those with severe disabilities who do not have good head movement capabilities, that opening and closing of the mouth could be used as an alternative to direct cursor movement in horizontal or vertical directions.

Figure 13: Two year old with cerebral palsy using CameraMouse (Betke et al., 2002)

Although the objectives of this study are very similar to those of our project, the limitations of this device are that it does not cater for those with dystonic movements and is complex to set up. The setup involves two computers and is designed to be used in a home environment, although a single-computer version was mentioned to be in development (Betke et al., 2002). The CameraMouse was tested with 20 people without disabilities and 12 people who had minimal motor control and an inability to speak; 10 with cerebral palsy and two with traumatic brain injuries. Two activities were undertaken by each group, the first involved a game where the user moved the cursor to the correct position on screen to “catch an alien” and the second involved the use of an on-screen keyboard to type the words “Boston College”. The CameraMouse was determined to be successful even though the speeds of activities were slower in comparison to use of a normal mouse. Nine of the testers with disabilities continued to use the CameraMouse with six being able to use the device to spell using the on-screen keyboard. The other three did not have a high enough level of muscle control to use the CameraMouse effectively.

A similar study conducted in 2008 by Varona et al. focused on the need to minimise calibration time of the system set-up for users. The system tracked the nose as the face detection point for similar reasons to CameraMouse, in addition to the fact that it cannot be occluded by facial hair or glasses. Initialisation of the system was conducted by the user positioning their head directly facing the screen without any form of rotation. It was noted that those with severe disabilities may require help with this to ensure optimal detection (Varona et al., 2008). This study involved both absolute and relative mouse tracking; absolute tracking mapped the nose position directly on the screen for those with good head movement, whereas relative tracking does not require as much accuracy and is more suitable for those with severe disabilities. An on-screen keyboard was utilised to conduct mouse events such as left-click, double-click and dragging operations.

A study by Morris and Chauhan in 2006, utilised tracking of nostrils rather than the edge of the users noses to determine head position. Testing of the system proved that the system was easy to use, required little calibration and although some jitter was present, it could be compensated for by visual feedback (Morris and Chauhan, 2006). Further research would need to be undertaken with people with severe disabilities to observe its benefits over alternative facial tracking points.

Systems which integrate the control of both mouse movement and left-click activation include the ‘Nouse’ (Gorodnichy and Roth, 2004) and ‘Facial Position Expression Mouse system (FM)’ (Bian et al., 2016). Nouse tracks the persons nose for mouse movement and presents a mouse click on detection of a double eye-blink. The double eye-blink is also used to help with calibration. FM on the other hand, tracks the persons nose and uses mouth movement for mouse control. The main advantage of FM over Nouse and other similar systems is that it utilises an infrared depth camera/ 3D camera. This provides better differentiation between the human face and the background environment, allowing for detection to not be largely affected by illumination and colour changes (Bian et al., 2016). This is similar reasoning as to why a 3D camera is utilised in this project, in addition to it not requiring any complex set-up or calibration.

A study by Tu et al, also produced an access solution which used mouth movements to control mouse events. An open mouth detection triggered a left- button mouse click and mouth corner stretching triggered a right-button click. This study however did not utilise a particular facial feature for tracking but instead identified key facial deformations to map facial features and then transformed general head movements into cursor movement. The study also compared three mouse control methods including direct mode, joystick mode and differential mode. The system was tested by playing simple games such as Minesweeper and Solitaire on the computer. Direct mode had low accuracy and differential mode, although beneficial for clicking large buttons on screen, required large head movements which make reading the screen difficult. Joystick mode navigated the mouse based on the direction of head movement and speed was based on the magnitude of head movement. This was found to be most intuitive and convenient mode for users, although not the fastest (Tu et al., 2007).

Another method for producing clicking functions of the mouse was proposed by Loewenich and Maire through use of voice commands. Users of their system can produce a voice command to perform mouse operations such as a single-click, double-click, click-and-drag or pick-up-and-release. The system was tested and proved to be robust, able to handle high levels of variations in lighting as well as background distractions. It does however require a calibration process and once again is not suitable for dystonic clients (Loewenich and Maire, 2007).

Some studies involving development of video-based cursor control have taken into consideration potential users with dystonic movements. For example, the Magic Key system as shown in Figure 14, uses a webcam to track the users nostrils similar to previous studies mentioned, however it has also included an option for reduced sensitivity to large involuntary movements (Fejtová et al., 2009). An infrared light is used to help illuminate the face and eyes to help with face tracking. Eye-blinking is the facial gesture used to control mouse actions, if the user has good control of individual left and right eye movements, there is the possibility for both a left-click and right-click function to be implemented. Dwelling can also be used as a potential mouse-click alternative, which provides a small window with options for single left-click, right-click, double-click or "drag-and-drop". A second study by Kjeldsen is also designed to benefit those with dystonic head movement as it uses a similar sensitivity adjustment to that of the Magic Key system. In addition to this, the system also introduces the addition of head gesture control to help with the set-up of the face tracking system. This was highlighted to be beneficial to the user as the head gesture mechanism could be used even when there was an error with specific feature detection (Kjeldsen, 2008). If for example face detection was lost due to large amounts of involuntary movement, this enables the system to be recalibrated without the need for external help.

Figure 14: Magic Key system set-up to track user's nostril movement (Fejtová et al., 2009).

Video-based access technologies which control cursor movement through detection of eye movement are called eye-gaze systems. Three systems designed for a person with a severe disability include EyeKeys (Magee et al., 2008), 14Controlsystem (Fejtová et al., 2009) and a third system which combines eye-gaze detection with head movement (Al-Rahayfeh, 2014). A comparison was conducted between the EyeKeys system (shown in Figure 15) and the CameraMouse resulting in some participants preferring EyeKeys as it did not require much head movement. On the other hand, some participants found the EyeKeys system mentally fatiguing and therefore preferred the use of the CameraMouse (Magee et al., 2008).

Figure 15: EyeKeys access solution set-up to detect users eye movement (Magee et al., 2008).

The 14Controlsystem as shown in Figure 16, consists of a small camera which is mounted to a spectacle frame which monitors the users eye movement through videooculograms, rather than through the use of a webcam directed at the face such as in EyeKeys. Another difference in this system is that clicks and double-clicks are generated through detection of different length blinks rather than through dwelling of the cursor (Fejtová et al., 2009). Finally, a system was developed which controls mouse movement through detection of eye-gaze direction in addition to head movement detected through flex sensors in a neck band. The outcome of testing this system resulted in a higher accuracy in cursor movement, however it has a very complex set-up, is not portable and requires high computational power (Al-Rahayfeh, 2014).

Figure 16: Access solution '14Control' which monitors users eye movement (Fejtová et al., 2009).

Finally, there were two other articles that created replication of cursor movement which were not video-based. These included a system which utilised infrared LED's on a computer monitor and a photo detector on the user's head to detect head movement (Evans et al., 2000), as well as a system which utilised electromyography (EMG) to control a cursor (Andrade et al., 2013). The infrared LED system was found to be more successful in joystick mode, similar to the discovery made by Tu et al. Trials by people with disabilities concluded that joystick mode which is alike to relative pointing mode of a mouse was preferred. This is due to the device mode having less interference from the environment and requiring less accuracy of head movement (Evans et al., 2000). The second system involving EMG required electrodes to be placed on the users face to detect facial muscle movements, which is not ideal for those with severe disabilities (Andrade et al., 2013). To control the cursor, users must produce an eyebrow lift followed by a period of relaxed muscle to create a ROTATE event which rotates the cursor to either DOWN, LEFT or RIGHT mouse movement. Continuous clenching of the teeth produces either a DOWN, LEFT or RIGHT mouse movement depending on the current movement direction of the mouse. Teeth clenching followed by relaxation of the muscles results in a single-click and finally continuous eyebrow raise movements result in an UP event. A Finite State Machine is responsible for converting the EMG signals into the relevant commands to control the computer mouse cursor (Andrade et al., 2013). A limitation of this device is that it cannot be used by those with dystonic movements or skin conditions.

2.2. Binary Switch Input Methods for Control of User Interfaces

Development of mouse presses and binary switch inputs via facial detection has also been a large area of research. Systems such as Blink Link and EyebrowClicker are examples of research developments which track voluntary long blinks and eyebrow raises, respectively, to trigger mouse clicks through use of a video camera (Grauman et al., 2003). Software such as these are often used in conjunction with software such as CameraMouse to replicate a mouse system, however could potentially be used for binary switch input.

A similar study utilised multiple 2D cameras to try and create a 3D detection of tongue protrusion for single switch access as shown in Figure 17 (Leung, 2010). This was designed to be more accurate and reliable over a wider range of angles than a single 2D webcam detection method for clients with severe spastic quadriplegia who have a large amount of head movement and to solve the difficulty of tracking facial expressions during these movements. Some limitations of this experiment were that this system is complex to set up and requires significant calibration. In addition to this, testing of the system was only undertaken with a single participant; a larger scale study would need to be conducted to determine if multiple cameras would benefit tracking of dystonic movement for switch input. Another device developed in recent years has utilised a similar 3D system but instead uses head position tracking rather than facial feature tracking to interface with a switch scanning software (Oppenheim, 2016). Once again, the limitation of this system is that it is not suitable for those without good control of their head and neck movements.

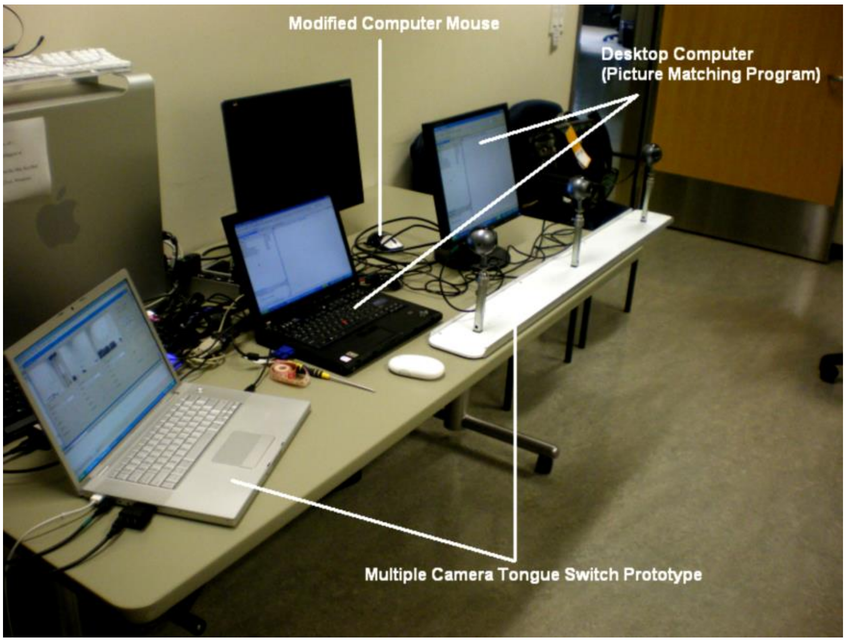

Figure 17: Set-up of multi-camera tongue protrusion switch application (Leung, 2010).

A study by Memarian et al in 2011, chose to utilise an infrared thermal camera to detect the opening and closing movements of the mouth as a binary switch input. Infrared thermography is not affected by variation in lighting or skin colour as it measures the radiation emitted from the surface of an object (Memarian et al., 2011). This 2D mapping of the face to detect mouth movement is a non-contact and non-invasive solution which was successful in creating an access pathway in the five experimental sessions conducted. The setup of the system is shown in Figure 18 and tests conducted included stimulus responses and word-matching tests through a simple switch input system. The client's performances improved over the five sessions as they became more comfortable with the system. The study also suggested future improvements to reduce current limitations of the system, so that it could be more beneficial to people with severe and multiple disabilities. These included: the implementation of automatic re-calibration of the system, creating an improved algorithm for tracking dystonic movements and use of multiple cameras to better detect involuntary movement to prevent loss of detection (Memarian et al., 2011).

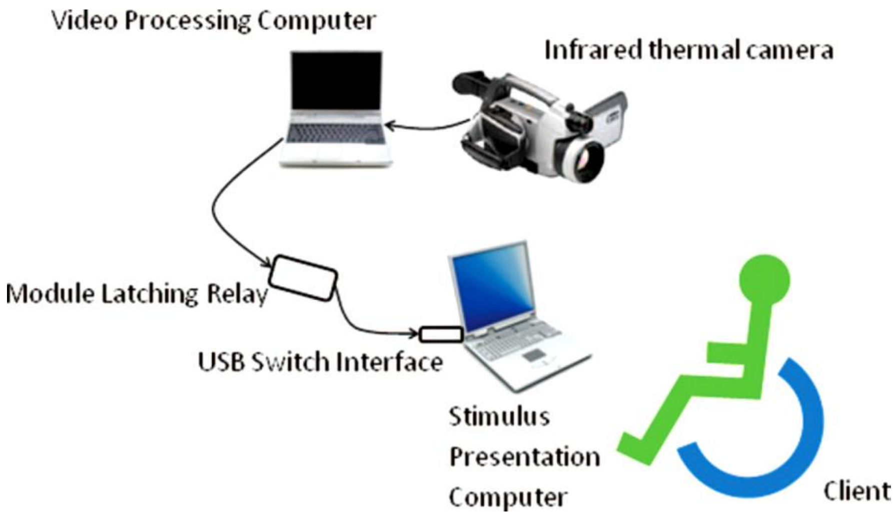

Figure 18: Setup of thermal camera trial (Memarian et al., 2011).

Lancioni et al. have also been working on the development of a video-based access technology for binary switch input. This study involved the use of a microswitch which is connected to a computer which monitors eyelid and mouth movements to produce a specific output when generated (e.g. music switched on/off). Small colour spots were used to help the webcam and computer system detect the facial movements. Three children with disabilities participated in the study, one focused on mouth closing, one on eyebrow lifting and one on eyelid closure movements. A software program using blob analysis technique was used to determine the change in position of the coloured spots and thus whether to produce a switch stimulus or not (Lancioni et al., 2011). The study resulted in some promising results however, further research into how socially acceptable the technology is and/or how to make the technology less obvious was required. Further studies on video-based microswitches by the group included an optic sensor placed on the cheekbone and a small sticker on the persons eyelid which was used to prevent interruption of the users visual functioning and was tested on three adults with multiple disabilities (Lancioni et al., 2012).

Apart from video-based solutions there are also many other forms of binary input switches which have been developed for people with severe and multiple disabilities in recent years. One example is a brain-computer interface which uses electroencephalography (EEG) to non-invasively detect neural rhythms and cortical potentials (Kohlenberg, 2007). Brain-computer interfaces at their current level of development unfortunately have many limitations including needing a long training period before effective use can be obtained. As a result of the complex signal processing, lagging of output signals also occurs and this subsequently reduces the speed and accuracy of the system. An alternative to EEG which results in a quicker system response is mechanomyography (MMG) which is similar to EMG detection of muscle movement signals. A system developed by Alves and Chau in 2011, allows for a switch output to be triggered when participants of the study contracted either their forehead, forearm or shoulder muscles. Unfortunately, the main limitation of this access solution is that the signal-to-noise-ratio is highly affected by involuntary dystonic movement which may be produced by those with severe disabilities (Alves and Chau, 2011).This will result in false activations of the binary switch which is not optimal. Another limitation of the system is that it involves electrodes being placed on the participants body which may not be suitable for some potential users.

A similar study conducted by Alves et al. introduced non-verbal vibration detection in combination with MMG detection. The aim of this access pathway is to provide two individual binary switches through use of only one input detection device, which in this case is a single contact microphone attached to the forehead of the user (Alves et al., 2010). The successful detection of the individual muscle movement and vocalisations is possible due to two detection methods – vocalisation vibrations are detected using a normalised cross-correlation method and muscle contractions by a continuous wavelet transform method (Alves et al., 2010). As the two signals do not have overlapping dominant bandwidths they do not interfere with each other.

Further study has been conducted on vocal cord vibration detection as an individual access method for those with severe disabilities. It is a beneficial method over other speech recognition switches due to the measurements being insensitive to environmental noise (Chan et al., 2010, Chau and Fairley, 2016). Sound is detected in speech recognition switches predominantly by close-talking microphones or a throat microphone, this makes them sensitive to noise from both the environment as well as speech generating devices. Sensitivity adjustments can reduce false activations however, this requires that the user speak more intensely and therefore the process becomes more fatiguing. Throat microphones reduce external interference but may cause misreading due to coughs, throat clearing, heavy breathing or involuntary dystonic movements (Chau and Fairley, 2016). However, the vocal cord vibration access solution shown in Figure 19, can detect periodic vibrations non-invasively by a dual-axis accelerometer placed on the anterior surface of the throat with a neckband. Vowels and hums create periodic vibrations which can be differentiated from aperiodic vibrations caused by coughs, swallows and throat clearances (Chau and Fairley, 2016). A prototype was made using a PIC microcontroller for clients to access a virtual on-screen keyboard. Testing procedures for the system included 3 participants, the first used binary-switching to engage in cause-and-effect activities for two sets of 30-minute sessions over a two-week period. Another client conducted environmental control tasks (e.g. turning on/off radio, changing channel etc.) for two 15-minute periods using both non-verbal vocalisations and humming. Finally, the third client used an on-screen keyboard and the access technology to write sentences including all letters of the alphabet, this was conducted in eight sessions over a two-week period. Another benefit of the non-invasive vocal cord vibration switch is that it is less fatiguing than a sound switch (Chan et al., 2010). One limitation however could be that the neck band could move with dystonic head movements and therefore not produce optimal outcomes. Nevertheless, this could be a potential solution for some people with severe disabilities without this limitation who have the ability to hum.

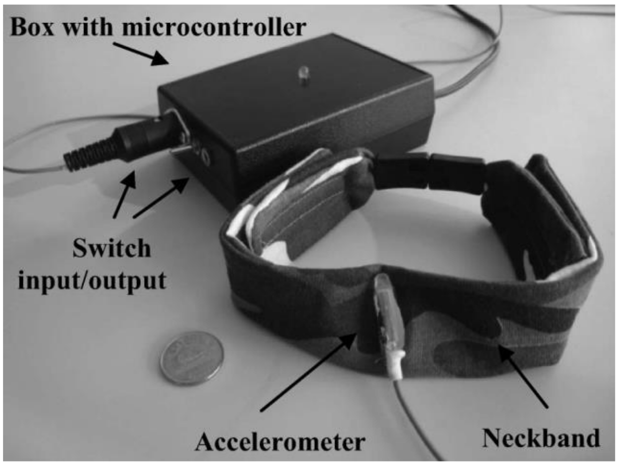

Figure 19: Throat vibration access solution system (Chan et al.,2010).

Dysarthria is a large reason why some people with severe disabilities are unable to effectively use speech recognition technologies, as they cannot produce consistent speech (Hawley, 2002). An improved speech recognition technology that has been developed to accommodate for dysarthric speech, allows for the differentiation between five vowel sounds to produce an input to an on-screen keyboard (Thalanki Anantha, 2013). The limitation with this system is that it is still a fatiguing process and a noisy solution which cannot be used in community environments.

Furthermore, for those with severe disabilities that have stable head and jaw movements a novel device which can control mouse button functions through a pop-up menu on the computer has also been developed. The system detects jaw vibrations produced by teeth clinking through positioning of an accelerometer against the users ear (Simpson, 2008). Vibrations produced by intentional tooth clicks are able to be differentiated from vibrations caused by both speech and head movements which make it suitable for those with involuntary head movements. The device is wireless and could be paired with other cursor movement technologies as an alternative computer access option.

Finally, two relevant articles describe developed access technologies for people with severe disability which utilise the tongue as a control site. Firstly, a mechanical switch for a specific client case was developed that produced a left mouse click on the clients computer when the switch was lifted by tongue protrusion and called for assistance from nurses in the care-home when the switch was depressed (Blain et al., 2010). Secondly, a Tongue Drive System (TDS) was developed for people with severe disabilities, to translate tongue movement into output commands without the need for the tongue to mechanically switch anything. This system is however quite invasive as it requires a small magnetic tracer to be attached by tissue adhesive to the users tongue or for them to receive a tongue piercing with a magnet integrated into the stud (Huo, 2011). Another alternative is for the user to have the biocompatible magnet implanted under the tongue mucosa. The movement of the magnet is detected by sensors and a signal processing unit is used to transform these into output controls to be generated on a user interface (Huo, 2011).

2.3. Summary

As indicated by this literature review, varying types of novel access technologies for those with severe and multiple disabilities have been developed and trialled. Video-based technologies have been a large area of research in recent years. This has included development of devices that replace mouse cursor movements, replicate mouse button operations, provide a combination of both or provide a single-switch activation method through detection of facial expressions or other body movements. The gap that this project fills is the need for a device for people with severe disabilities which addresses the limitations of previous work in the field, which doesn't require calibration and can work with people with dystonic movement.

Many of the systems discussed in this literature review involved use of multiple computers or devices resulting in a complex set up. This gap will be filled by the project prototype implementing a portable system which can be utilised in both the home and community environment and easily mounted on a wheelchair. In addition to this, many of the technologies mentioned involved a lengthy calibration process - in particular those using a 2D web camera, this increases the difficulty of use of the system and decreases the user's independence in the set-up of the technology. Infrared depth cameras/ 3D cameras were used in a few of the studies reviewed, this project will also utilise this form of camera as it provides automatic calibration, easy set-up and better face-tracking capabilities. Dystonic head and neck movements are present in some cases of severe disability such as cerebral palsy. Only a few studies accounted for this in their access technology development. This project aims to minimise the effect of dystonic movements on the effectiveness of the system. Finally, very few of the technologies provided the option of various facial-feature tracking points, whereas this project plans to have a variety of facial feature tracking options to make it a more inclusive software. Rather than catering for only specific limitations, it will be flexible enough to be adjusted to the changing needs of various users over their lifespan, as well as when they reach different levels of fatigue.

Therefore, although many developments have been made in the field, each with their advantages and disadvantages, none are completely unique to what is developed in this project. There is a definite need for further research and development in this area. Currently there is no other commercially available system that has the required specifications – low cost, easy set-up (no calibration), non-contact and non-invasive face tracking switch system that interfaces with an existing user interface such as switching-scanning software. It also has the ability to track dystonic movements and provides a variety of facial expression options to be chosen as the switch control site depending on the user's capabilities and needs.

3. System Design and Development

This chapter will introduce the technology of the developed switch access system - named 'FaceTracker'. The Intel RealSense SR300 camera's capabilities, functional requirements and the current suitable laptops/tablets for the developed system are discussed, followed by a description of the design and development of the system's software.

3.1. Hardware

3.1.1. Intel RealSense SR300

Figure 20: Intel® RealSense™ SR300 camera (Intel, 2017a).

The Intel® RealSense™ SR300 camera (Figure 20) is an upgraded version of the Intel® RealSense™ F200; the world's first and smallest integrated 3D depth and 2D camera module (Intel, 2017a). The camera is designed for developers to create applications using the capabilities of the Intel RealSense SDK algorithms, these include: hand-tracking, speech recognition, face-tracking, background segmentation and object-tracking. The 2D colour camera can operate both independently and/or together with the infrared camera to create colour, infrared and depth video frames as shown in Figure 21.

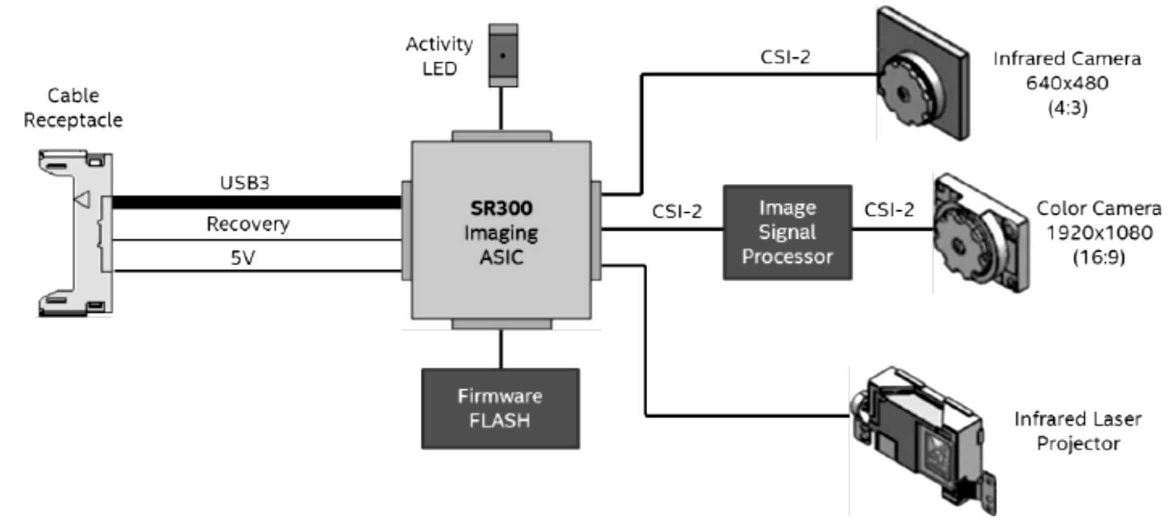

Figure 21: Intel RealSense SR300 3D imaging system (Intel, 2016a).

Colour video frames are generated through the capture of chromatic pixel values by a chromatic sensor which are then processed through a signal processor and the imaging ASIC to create a colour image frame (Intel, 2016a). For depth and infrared video frames, a set of predefined coded IR vertical bar patterns with increasing spatial frequency are projected onto and warped by the scene being detected, before being reflected back to the IR camera where they are captured again (Intel, 2016a). The monochromatic pixel values captured are then processed by the imaging ASIC to generate a depth frame as shown in Figure 22. Multiple colour, depth or infrared frames are added together to make up a video stream which is then transmitted via USB 3.0 to the computer system.

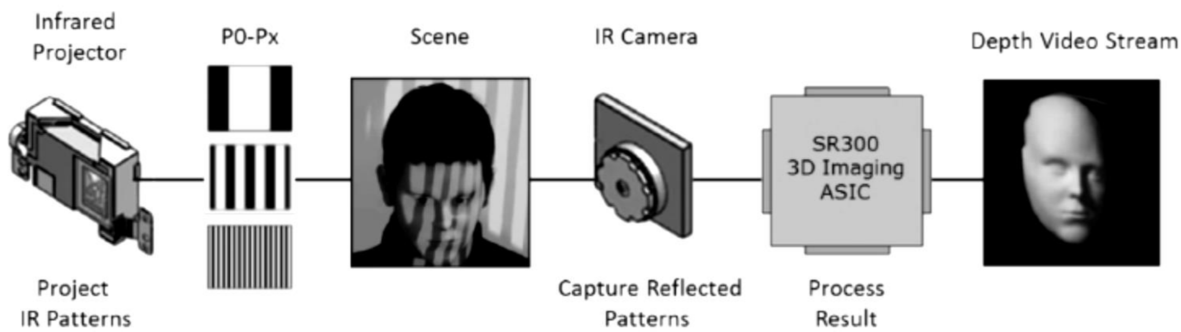

Figure 22: Intel RealSense SR300 depth stream data flow (Intel, 2016a).

3.1.2. Intel RealSense SR300 Properties (Intel, 2016a)

Some important camera details / properties are listed below:

- Approximate cost of device: $109.00 AUD.
- Face-tracking feature works when user is between 0.2m – 1.2m from camera.
- Up to 60FPS depth stream capturing at 640 x480 (VGA) resolution.
- Class 1 Laser Compliant (below limits for which biological hazards have been established).
- Typical power consumption for running colour and depth stream is 1800mW.
- 110mm width x 12.6mm height - small and compact for portability purposes.

3.1.3. Intel RealSense SR300 Camera Requirements (Intel, 2016a).

For the camera to run without any issue, Intel has recommended the following hardware and software specifications be met by the utilised computing device:

- 6th generation Intel Core^{TM} processor or higher.
- 150MB free hard disk space, 4GB random-access memory (RAM).
- Free USB 3 port to support bandwidth needed by camera- must connect directly to system (cannot use hub).
- Microsoft Windows 10 (build 10586 and above).
- Installation of Intel Depth Camera Manager (DCM) to enable camera capabilities.

3.1.4. Suitable Tablets/Laptops

Augmentative and alternate communication (AAC) devices are often used by those with severe or multiple disabilities for computer access; they are designed with those who have communication limitations in mind. This means that they have the advantage of being more durable, are easily mounted, possess good speakers for synthesising text to speech and often come with communication software. Additionally, AAC devices also often have built in environmental control ability (Infrared and/or Z-wave) or they have easy access to attach an environmental control unit (ECU) via USB or switch input areas. They also may come with built in access methods such as Eye-gaze systems.

Unfortunately, the current AAC devices on the market either do not have a USB 3.0 Port (only recent devices have begun to be released with this) or they do not meet the other camera requirement of CPU power equivalent to 6th generation Intel Core processor or higher as shown in Table 3.

Table 3: Specifications of commercially available AAC devices with USB 3.0.

Name	**Processor Type**	**Cores**	**Threads**	**Base Freq. (GHz)**	**Max Freq. (GHz)**	**Cache (MB)**	**RAM (GB)**	**1x USB 3.0 port**	**Other USB ports**	**Operating system**
Grid Pad Pro 18 (17.3")	Intel® Pentium® processor J3710	4	4	1.60	2.64	2	8	Yes	2x USB 2.0	Windows 10
Grid Pad Eye 18 (17.3")	Intel® Pentium® processor J3710	4	4	1.60	2.64	2	8	Yes	2xUSB 2.0	Windows 10
Tobii I-12+ (12.1")	Intel® Celeron Quad Core Processor J1900	4	4	2.00	2.42	2	4	Yes	2x USB 2.0, 2x 3.5mm switch input	Windows 8.1, 10

Therefore, further research went into suitable 2-in-1 devices as an alternative solution to the common AAC devices used for access. 2-in-1 devices are much more desirable than laptops due to their flexibility in screen set-up and/or their ability to remove the keyboard for easier mounting. These devices not only needed to have the appropriate processing power and USB 3.0 port for the Intel RealSense SR300 Camera but also additional USB ports which could be used to connect additional switches and/ or ECU's.

Laptops with built in Intel RealSense cameras were also researched, however it was decided that having an external camera system gave greater flexibility of system use. It not only gave more possibilities for setup and positioning of the system for varying client needs but also the benefit that a new computing device would not need to be purchased when updated versions of the camera are released; the new camera can be simply plugged into the same device.

In initial project work undertaken in 2016, a Microsoft Surface Pro 3 i7 was used with the Intel RealSense SR300 to complete the hardware components of the system. However, Intel has since upgraded their recommended hardware specifications from a minimum of 4th generation Intel Core^{TM} processor to a 6th generation. As a result of this and due to available resources a Microsoft Surface Pro 4 i7 was utilised as an upgrade to the Microsoft Surface Pro 3. The specifications of both devices can be compared in Table 4 below.

Table 4: Comparison of Microsoft Surface Pro 3 and Surface Pro 4 specifications.

Name (screen size)	**Processor Type**	**Cores**	**Threads**	**Base Freq. (GHz)**	**Max Freq. (GHz)**	**Cache (MB)**	**RAM (GB)**	**1x USB 3.0 port**	**Other USB ports**	**Operating system**
Microsoft Surface Pro 3 i7 (12”)	Intel® Core™ i7-4650U	2	4	1.70	3.30	4	8	Yes	None*	Windows 10
Microsoft Surface Pro 4 i7 (12.3”)	Intel® Core™ i7-6650U	2	4	2.20	3.40	4	8/16	Yes	None*	Windows 10

*Windows Surface 2-in-1 devices also has the possibility of using a Surface Dock for an additional 4 USB 3.0 ports, testing of a similar device ‘Surface Pro 3 Docking Station’ is discussed in section 5.11.

It can be seen that the Surface Pro 4 i7 has a better processing power than the Surface Pro 3 i7 with an additional 0.5GHz in base frequency and an additional 0.1GHz at maximum frequency when Intel Turbo Boost Technology is implemented- this allows for the processor to increase its clock speed when required (Parkinson, 2013). The main benefit of i7 processors over i5 is that in addition to Turbo Boost they also have Intel Hyper Threading Technology which allows for multiple threads to run simultaneously on each core, increasing performance levels (Parkinson, 2013). The amount of RAM changes the amount of interaction with the hard drive the device has for commonly used data. Similarly, cache minimises interaction with RAM for commonly used data, therefore a higher amount of cache means data will be processed faster by the device (Parkinson, 2013).

Table 5: Comparison of commercially available 2-in-1 devices with a USB 3.0 port.

Name (screen size)	Processor Type	Cores	Threads	Base Freq. (GHz)	Max Freq. (GHz)	Cache (MB)	RAM (GB)	1x USB 3.0 port	Other USB ports	Operating system
Microsoft Surface Pro 4 i5 (12.3”)	Intel® Core™ i5-6300U	2	4	2.40	3.00	3	4/8	Yes	None*	Windows 10
Microsoft Surface Book (13.5”)	Intel® Core™ i5-6300U/ Intel® Core™ i7-6600U	2	4	2.40/2.60	3.00/3.40	3/4	8/16	Yes	1xUSB 3.0 *	Windows 10
Lenovo Miix 520 (14”)	Intel® Core™ i5-7200U / Intel ® Core™ i7-7500U	2	4	2.50/2.70	3.10/3.50	3/4	8	Yes	1xUSB 3.0, 1xUSB Type C	Windows 10
Lenovo Miix 720 (12”)	Intel® Core™ i5-7200U/ Intel ® Core™ i7-7500U	2	4	2.50/2.70	3.10/3.50	3/4	8	Yes	1xUSB 2.0, 1xUSB 3.1 (type C)	Windows 10
Lenovo Yoga 520 (14”)	Intel® Core™ i5-7200U/ Intel ® Core™ i7-7500U	2	4	2.50/2.70	3.10/3.50	3/4	8	Yes	1xUSB 3.0, 1xUSB Type C	Windows 10
Lenovo Yoga 910 (13.9”)	Intel® Core™ i5-7200U/ Intel ® Core™ i7-7500U	2	4	2.50/2.70	3.10/3.50	3/4	8/16	Yes	1xUSB 2.0, 1xUSB 3.0	Windows 10
Acer Spin 5- SP513-52N-33SN (13.3”)	Intel® Core™ i5-8250U	4	8	1.60	3.40	6	8/16	Yes	1xUSB 2.0, 1xUSB 3.0	Windows 10
ASUS VivoBook Flip 14 (14”)	Intel® Core™ i5-7200U / Intel ® Core™ i7-7500U	2	4	2.50/2.70	3.10/3.50	3/4	8/16	Yes	2xUSB 2.0,1x USB 3.0 Type C)	Windows 10

*Windows Surface 2-in-1 devices also has the possibility of using a Surface Dock for an additional 4 USB 3.0 ports, testing of a similar device ‘Surface Pro 3 Docking Station’ is discussed in section 5.11.

3.2. Software

3.2.1. Improvements from ‘Proof of Concept’ Prototype

The integrated development environment (IDE) used to develop the FaceTracker application was Microsoft Visual Studio 2017. As mentioned in section 1.8, the proof-of-concept prototype created a basic interface application which used the RealSense SDK to create an interface between the 3D camera and Grid 3 switch scanning software. vJoy is an open source virtual joystick device driver developed by Shaul Eizikovich, that fills the gap between a device that is not a joystick and an application that requires a joystick input (Eizikovich, 2016a). In this case it was used as part of the application to create a link between the input being detected from the camera; a mouth open expression reaching a threshold greater than 20 out of 100, and converting this into a joystick button press which was detected by Grid 3 as a switch input. A device used for monitoring the vJoy device is shown in Figure 23, it displays user input from joystick axis movement, point of view (POV) movement and button activations; with activated buttons shown in red. For the ‘proof of concept’ application a single button was used, therefore, to test the application was working successfully, button one would be observed for activation (i.e. turning red) when a mouth open expression was undertaken.

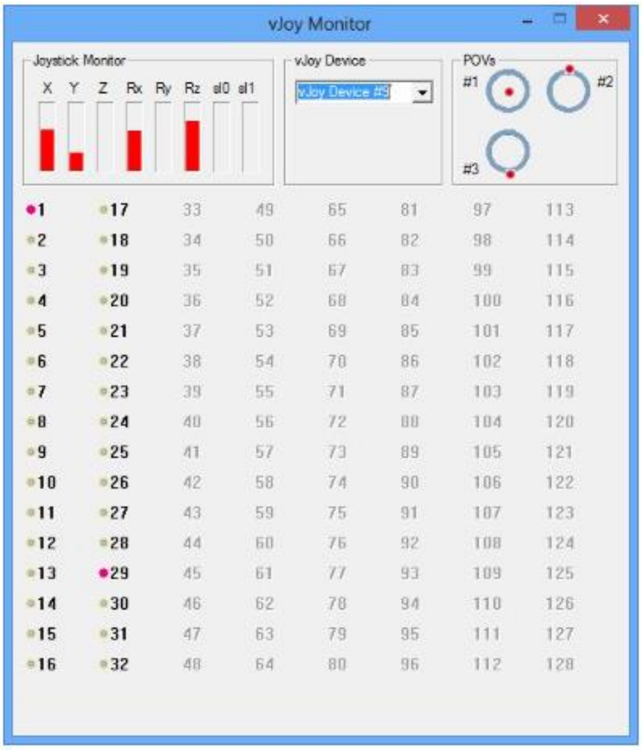

Figure 23: VJoy Monitor – shows activated (red) and inactivated buttons (grey) (Eizikovich, 2016b).

The first change made to the application from the first prototype was a conversion from C++ to C#. This was undertaken due to the need for a user-friendly graphical user interface (GUI) to be developed. After research into potential solutions, the Windows Presentation Foundation (WPF) model was decided on due to restrictions of support from the SDK and ease of understanding and grasping of a new skill in application development. The application kept a similar coding layout in its depth streaming video to the prototype when converted to WPF in C# and Extensible Application Markup Language (XAML) from the basic C++ application as shown in Figure 24. See Appendix A for a code sample from this section of the application.

One of the problems with the initial prototype was that there was lagging and occasional freezing of the program after large amounts of head movement. The upgrade in processing power from Surface Pro 3 to Surface Pro 4 helped to address this issue. Additionally, changing the camera property: 'SetIVCAMMotionRangeTrade Off' to a value of 0, allowed for a high range of motion to be kept up with, at a cost of the camera not detecting at such a far range.

The second issue from the 'proof of concept' prototype which was addressed in this version was that of talking, smiling and laughing by the user setting off accidental switch activations. To fix this when detecting the 'mouth open' expression, the 'smile' expression was also detected. When allowing for a switch activation to be made, the 'mouth open' expression was not only required to reach the set threshold, but the 'smile' threshold also had to be equal to zero. This ensured that the switch would only be activated if a direct opening and closing of the mouth action was performed.

Following this, a new GUI was created using XAML and C# which incorporated a wider range of choices in expression to select from, including:

- Mouth Open (only choice in proof-of-concept prototype developed in 2016)
- Tongue Out
- Smile
- Eyebrow Raise
- Kiss
- Puff Left Cheek
- Puff Right Cheek

The design and development of the FaceTracker GUI will be further explained in section 3.2.2.

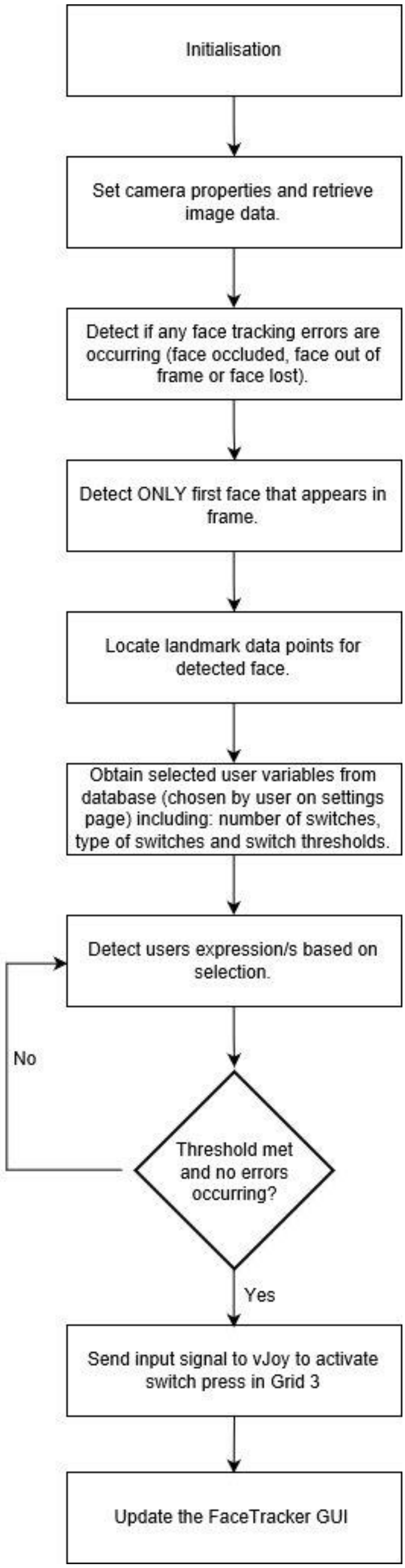

Figure 24: Flow Chart of updated video window code design.

3.2.2. FaceTracker GUI

One of the main aims of the creation of the new user interface was so that users could save their settings and adjust them when necessary. Therefore, the home page (shown in Figure 25) gives the option to change the current user to a different saved profile (or create a new user), as well as the ability to change the settings of the current user. The option of 'let's go' minimises the window to allow for the user to use the FaceTracker application without the main window taking up vital space on the desktop. Additionally, when the application is started, it will automatically begin tracking based on the last user's settings.

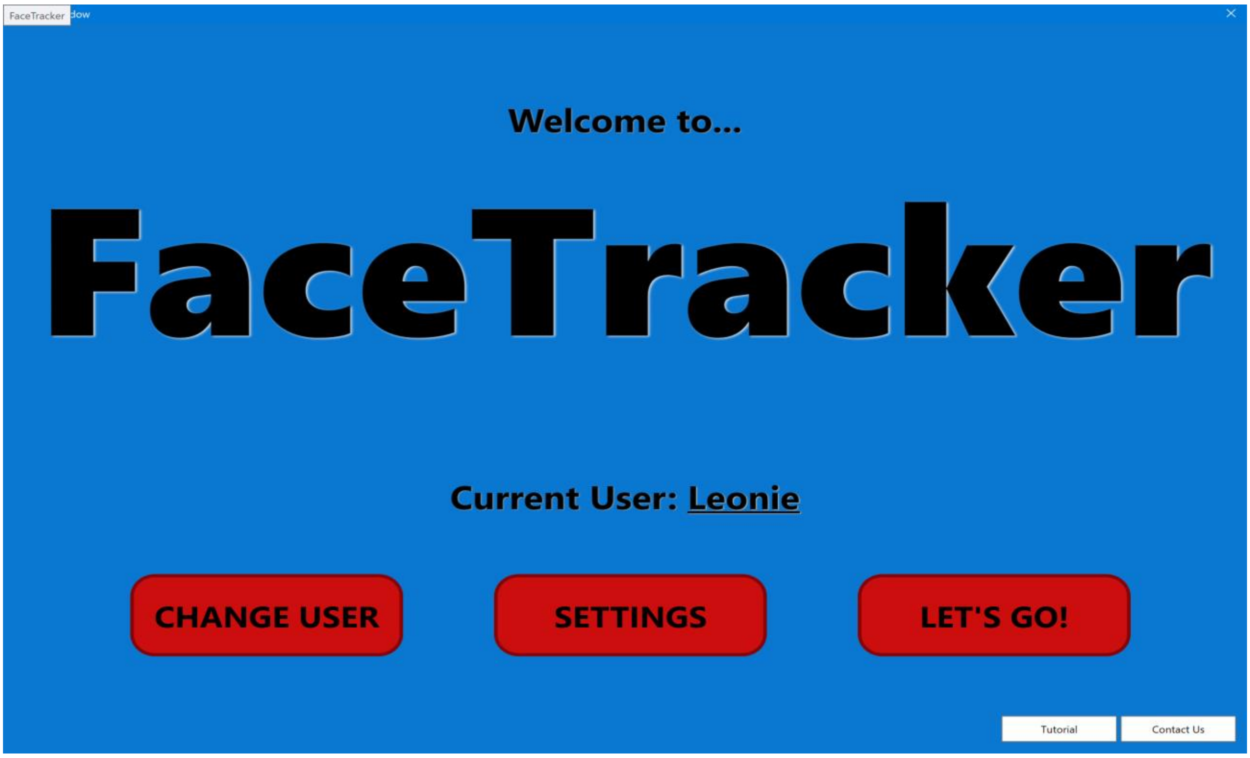

Figure 25: Home page of FaceTracker application GUI.

If the user presses the 'change user' button, they will be taken to the window shown in Figure 26.

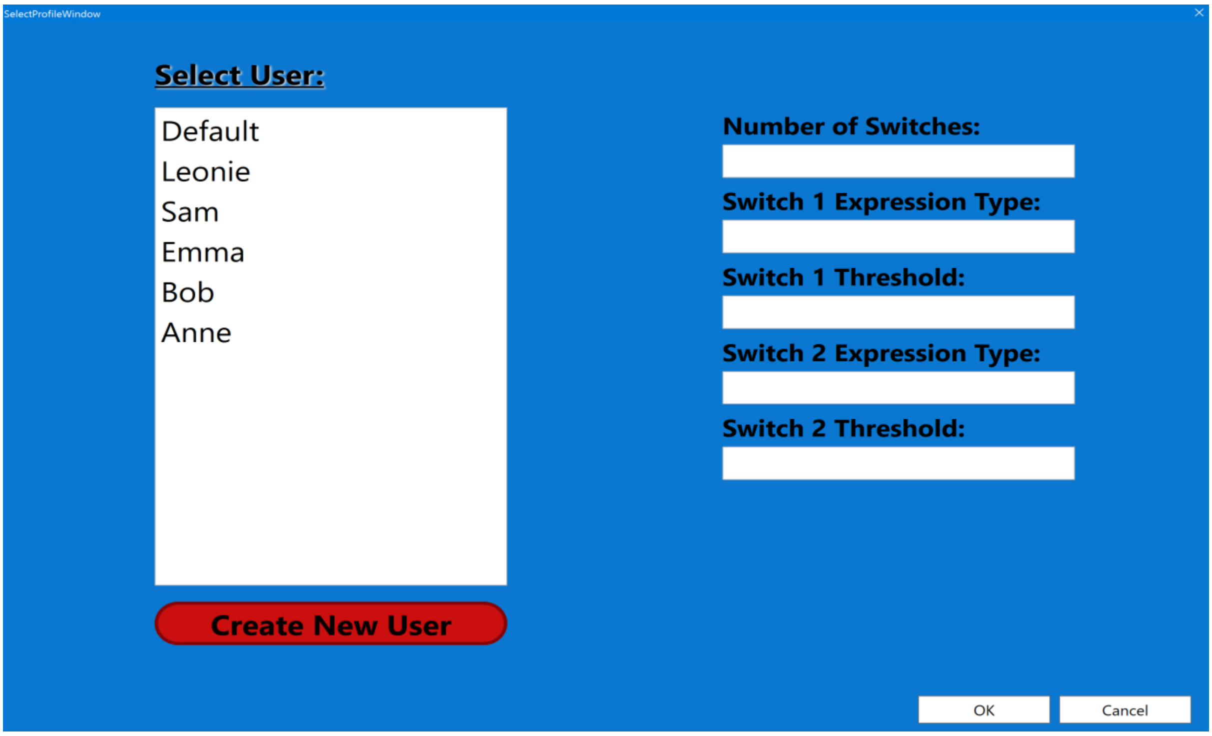

Figure 26: Select user profile window of FaceTracker application.

This allows for the user to select from previously made user profiles, with the settings shown in the text boxes to the right-hand side. By selecting the 'OK' button the user will return to the home page where the application will now be tracking based on the selected users profile settings. The advantage of having the ability to save user profiles is not only so that multiple people could use the application, but also for a single user to save different settings based on their fatigue levels and/or the appropriateness of expression use in certain environments. For example, the use of the 'tongue out' expression may not be very appropriate in a community/school environment. Alternatively, if the user pressed the 'create new user' button, they would be prompted to enter a name for their new profile through a pop-up as shown in Figure 27, before being taken to the settings window of the FaceTracker application as shown in Figure 28.

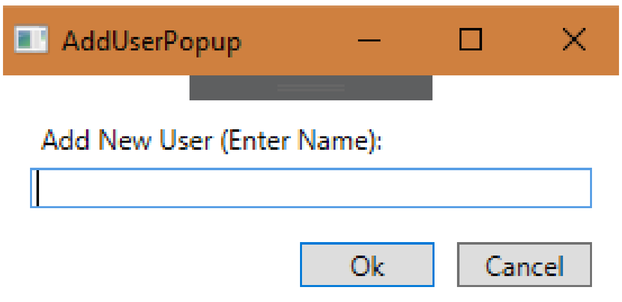

Figure 27: Add user pop-up window

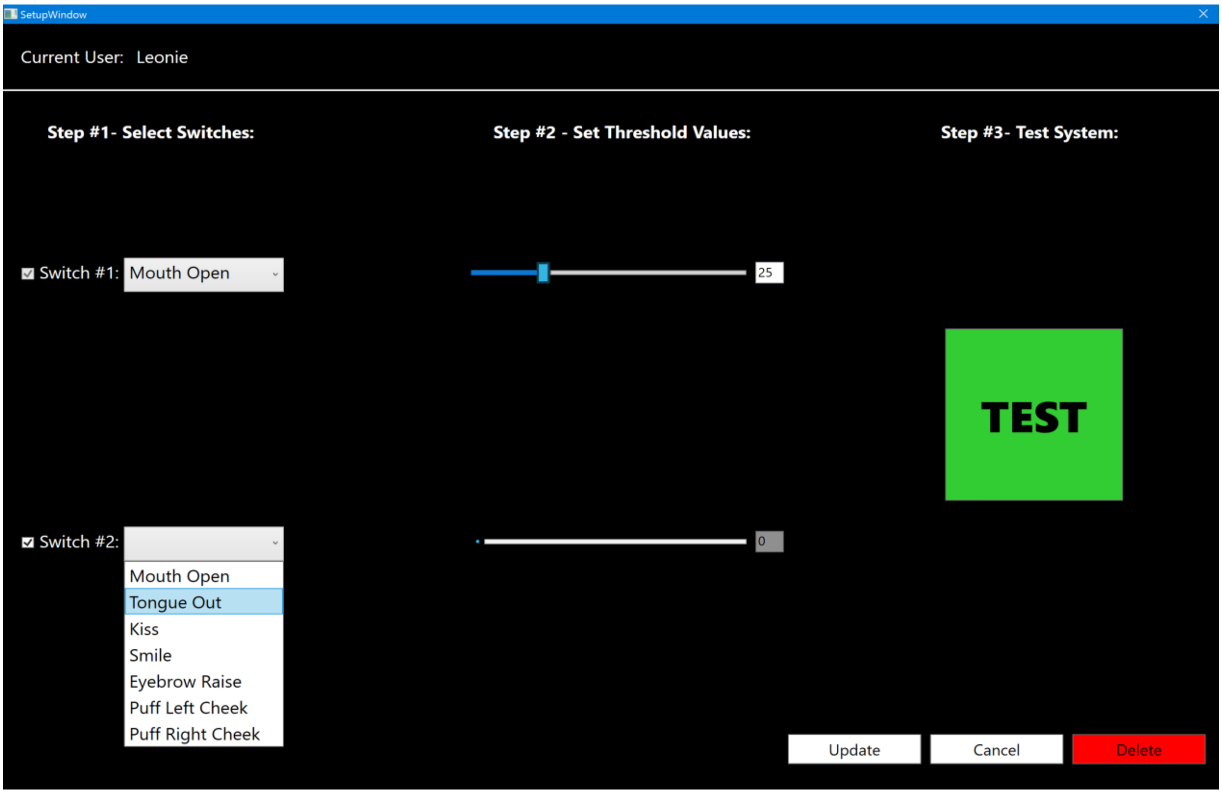

Figure 28: Settings window of FaceTracker application.

When a new profile is created, a set of default values are used: single switch, mouth-open expression with a threshold of 25. These settings are easily changed by checking the box next to switch #2 to add a switch or by changing the selected expressions via the drop-down boxes. Only the mouth open and smile expressions have the ability to change threshold - this can be done by moving the slider or entering the value out of 100 into the textbox provided. The built-in algorithms of the Intel RealSense SDK have the ability to detect levels of mouth open and smile expressions from very small to very large – the greater the value the more forceful the expression. In comparison, tongue out, kiss, eyebrow raise and puff cheek expressions have a binary switching threshold value directly between 0 and 100 and therefore step #2 will be disabled if these expressions are selected. It is very important for the user to find the most appropriate expression for their abilities, as well as finding a suitable threshold so that the expression can be repeated without fatiguing too quickly but also not too small that talking may still set it off.

In order to be able to test the suitability of selected settings without returning to the settings window several times, by pressing the 'test' button on the settings window the selected settings can be tested without changing the currently set settings of the user. This is also an advantage of the system as the user is able to independently change/adjust their profile settings and test them by using Grid 3 with their current expression and threshold, and this will not be permanently changed until the user selects the ‘update’ button.

The test window basically has the same function as a video stream – it is tracking the users face so that when the user, for example in Figure 29, opens their mouth greater than the threshold of 25, the circle for switch 1 will turn green and play an audio beep to replicate the activation of a switch. The screen also shows if any errors are occurring through the coloured border and message in the top left corner; the border will display red if any error in face-tracking is occurring. As previously mentioned, once the user is happy with their selected settings by pressing the ‘update’ button they will confirm that they wish to use these settings and will return to the home page (Figure 25). However, if the ‘delete’ button is pressed this users profile will be deleted and the user will return to the select user profile window (Figure 26).

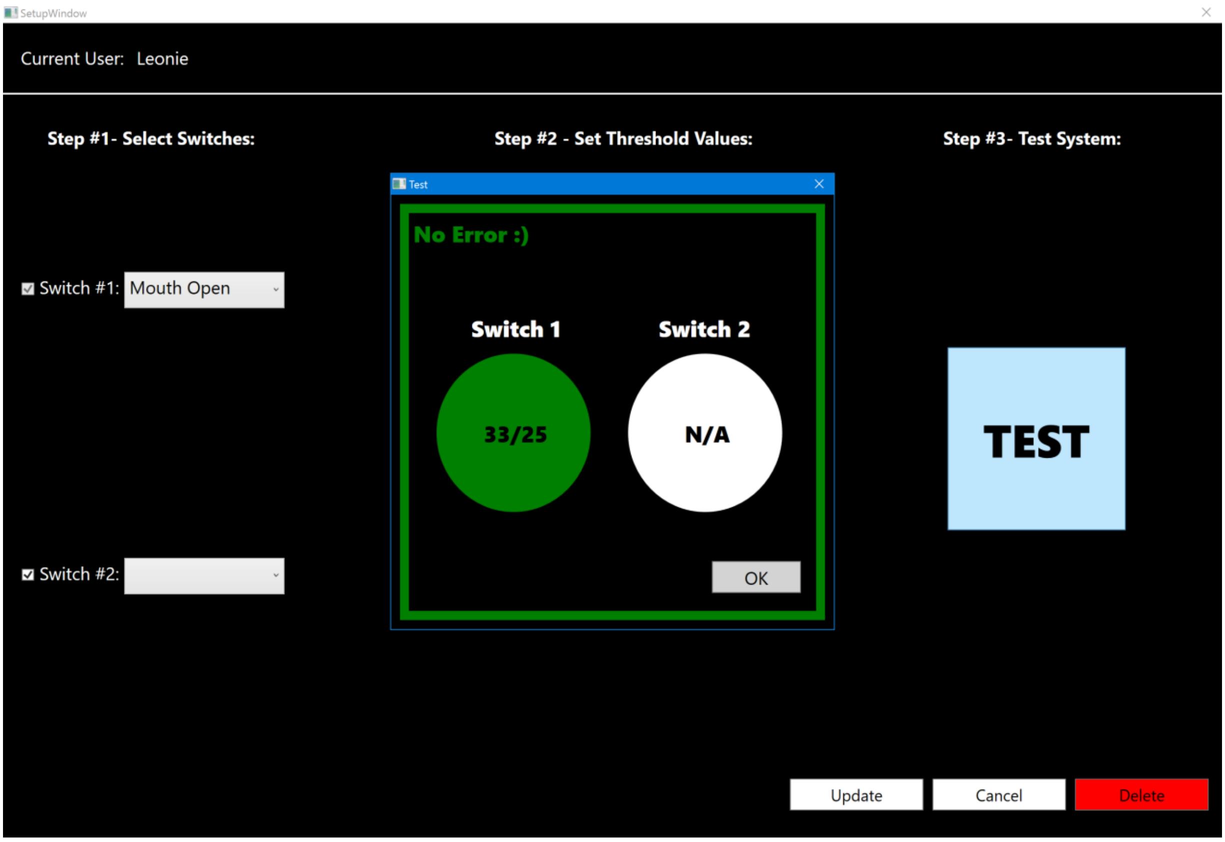

Figure 29: Test window of FaceTracker application.

To enable this communication between windows and user settings an open source database called SQLite was utilised. SQLite was chosen due to it being open source and its ability to be used without a server and can be used cross-platform (SQLite, 2017). Three tables were made: the first called ‘UserProfiles’, the second called ‘SelectedUserProfile’ and the third called ‘TestUser’, as shown in Figure 30. Each of these tables had columns to hold variables including: the name of the user, the number of switches they wish to use (one or two), the first switch expression type, the first switch expression threshold to activate the switch, the second switch expression type (if selected) and the second switch expression threshold.

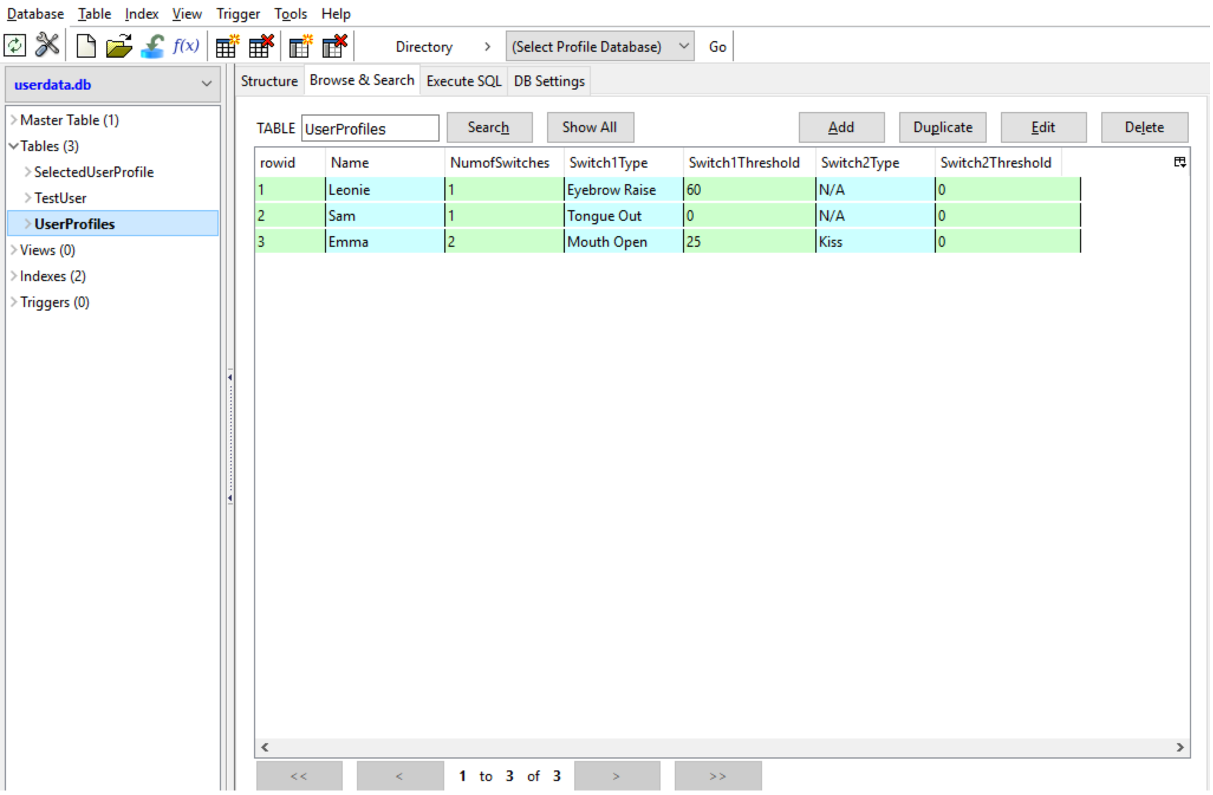

Figure 30: SQLite database - tables utilised in FaceTracker application.

The ‘UserProfiles’ table holds all the settings for all the created and saved user profiles of the application. ‘SelectedUserProfile’ holds the settings for the current user of the application and is where the video stream obtains its data values from and knows what to detect. Finally, the ‘TestUser’ table contains the values temporarily selected to try out in the test window, these settings are either replace the ‘SelectedUserProfile’ data if the user updates their settings or are deleted.

As previously mentioned another important aspect of this application is the ability for it to not take up any room on the screen due to Grid 3 switch scanning software already takes up a lot of room. To make it easier for the user, the application integrated the use of a Taskbar Icon with a context menu with options to: pause/unpause tracking, show the video window for visual feedback, access the home window and to quit the application. This means that when the ‘let’s go’ button is pressed all windows will close but face-tracking will continue to run in the background. In order to pause, show the video or change user or settings, the user will need to click on the taskbar icon, as shown in Figure 31.

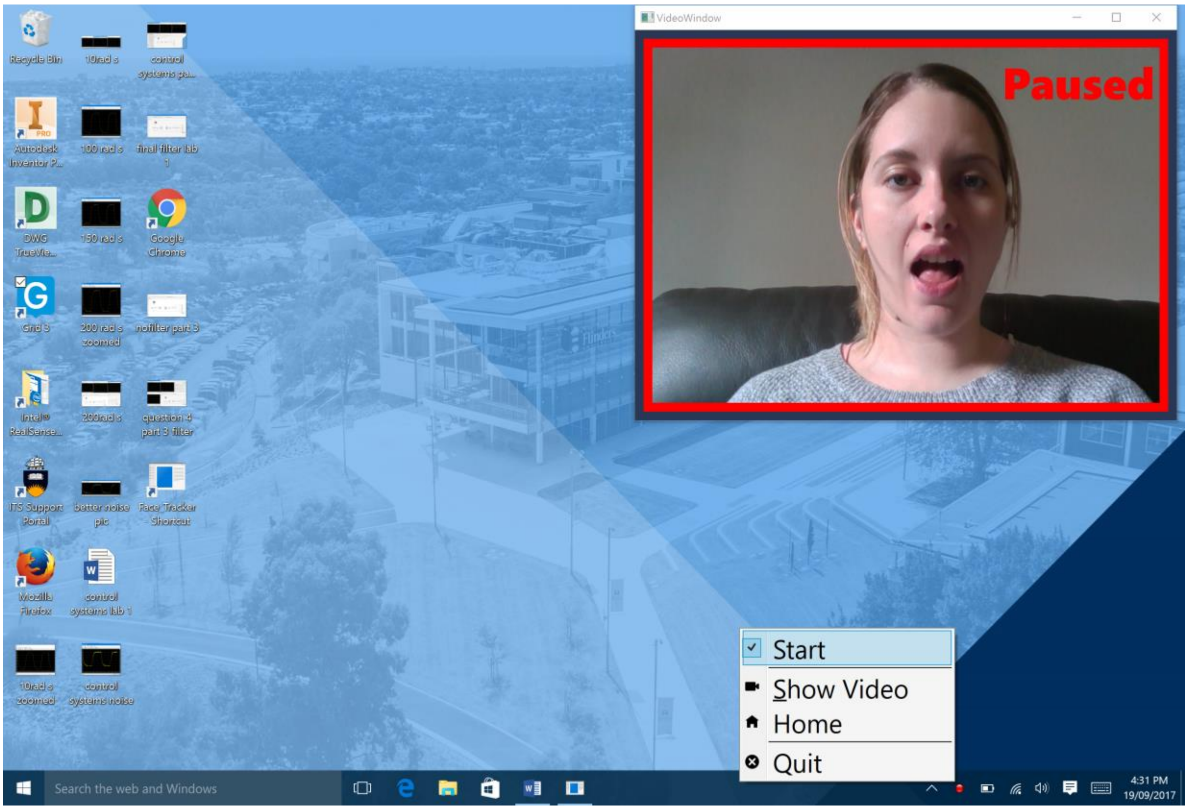

Figure 31: Taskbar icon and context menu - showing the selection of the pause camera function.

Figure 31 also shows how the video window gives the user feedback on the system being paused. Similarly, Figure 32 shows an example of the user feedback given when the video is not paused. The video screen displays a green border and ‘no error’ message in the bottom left-hand corner to alert the user that face-tracking is occurring without error. It also shows the selected switch expressions in the top left-hand corner, with switch one being displayed in white and switch two in black. The current value of expression is also displayed, with a ‘switch!’ text being displayed in the top right-hand corner when this value reaches over the set threshold as shown for the mouth open expression in Figure 32 and for tongue out in Figure 33.

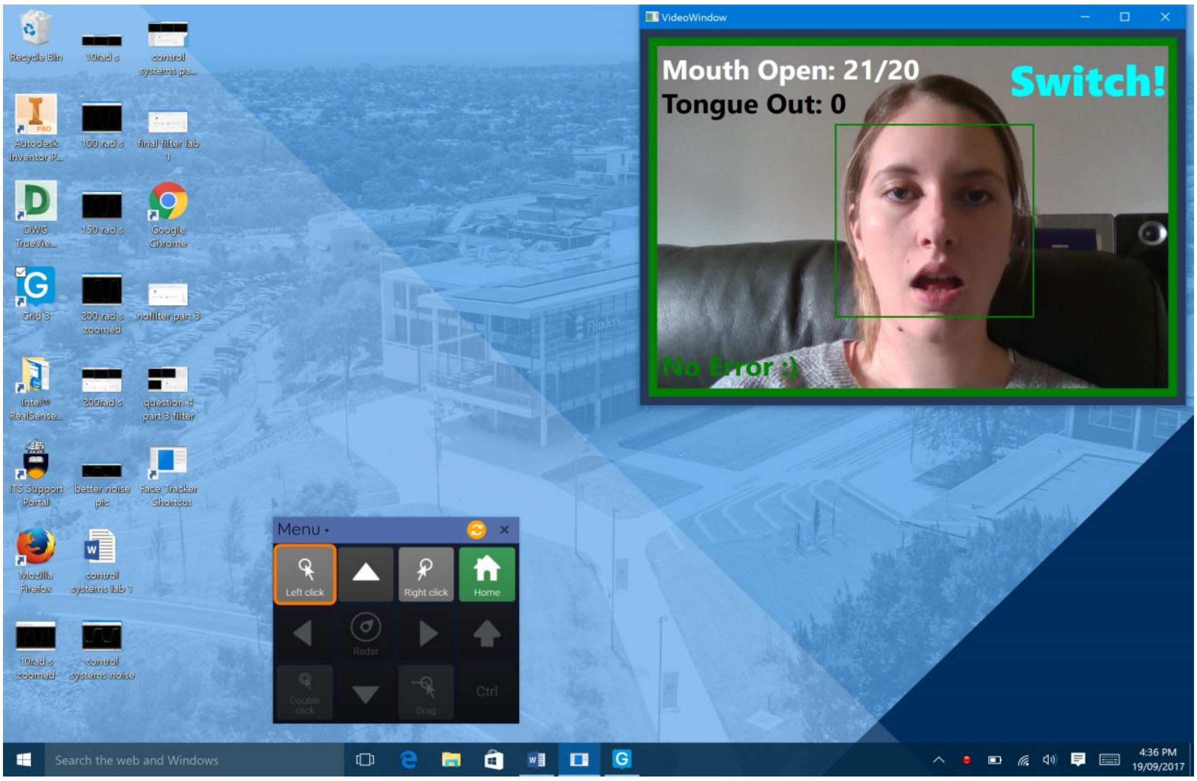

Figure 32: Video window user feedback - switch activation for mouth open expression.

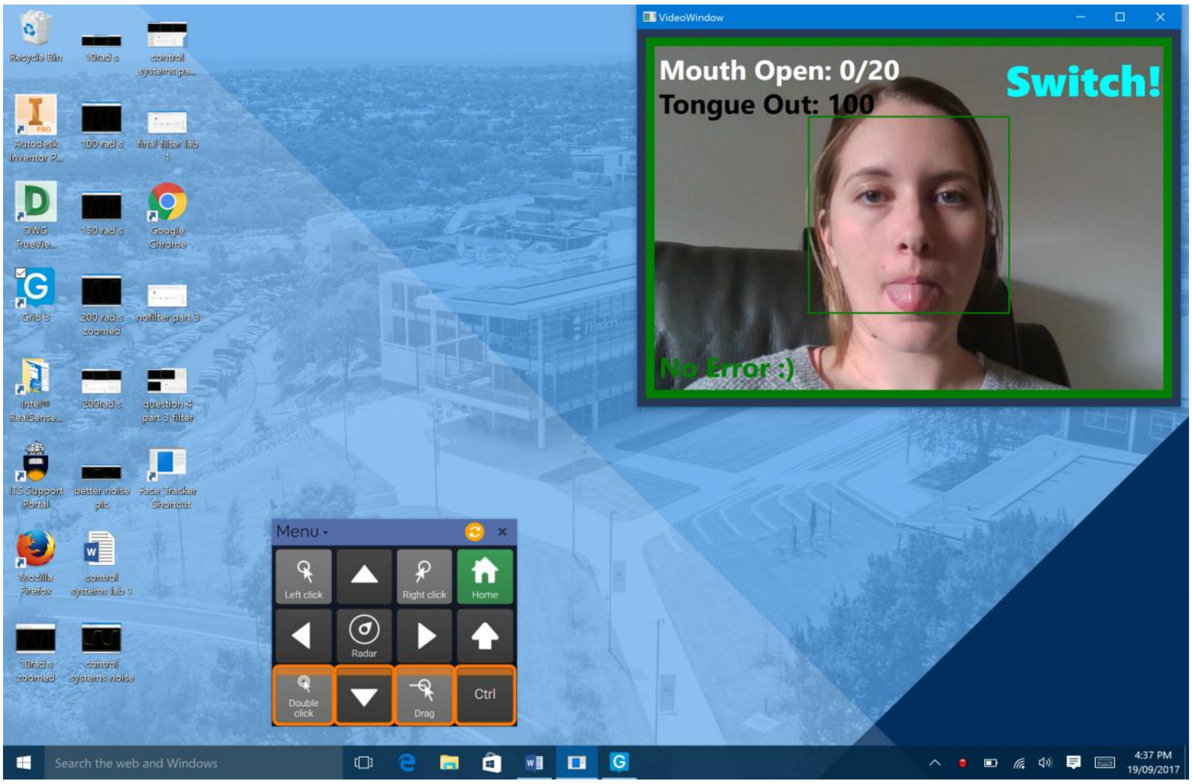

Figure 33: Video window user feedback - switch activation for tongue out expression.

Additionally, the video window also provides user feedback on errors which may be occurring. These include: ‘face occluded’ as shown in Figure 34, ‘face out of frame’ as shown in Figure 35 and ‘face lost’ as shown in Figure 36. The ‘face occluded’ error occurs when the user has something placed in front of their face that will interfere with proper expression detection. Similarly, the ‘face out of frame’ error will occur when any part of the user’s face is not in the frame due to improper positioning in front of/away from the camera. Finally, the ‘face lost’ error is caused when the camera cannot detect the face – due to the user turning their head away from the camera or when the face can’t be differentiated from the background due to bright light or glare interference.

The ‘face occluded’ and ‘face out of frame’ errors cause a red border to show around the image stream, as well as around the user’s detected face as shown in Figure 34 and Figure 35. However, the ‘face lost’ error only shows a red border around the user’s face and a green border around the main image as shown in Figure 36. It was found that when the ‘face lost’ error occurred that the expression threshold was still detected for the most part – just not as consistently as when no error was occurring, so it was important to differentiate that switching could still occur when this error was shown.

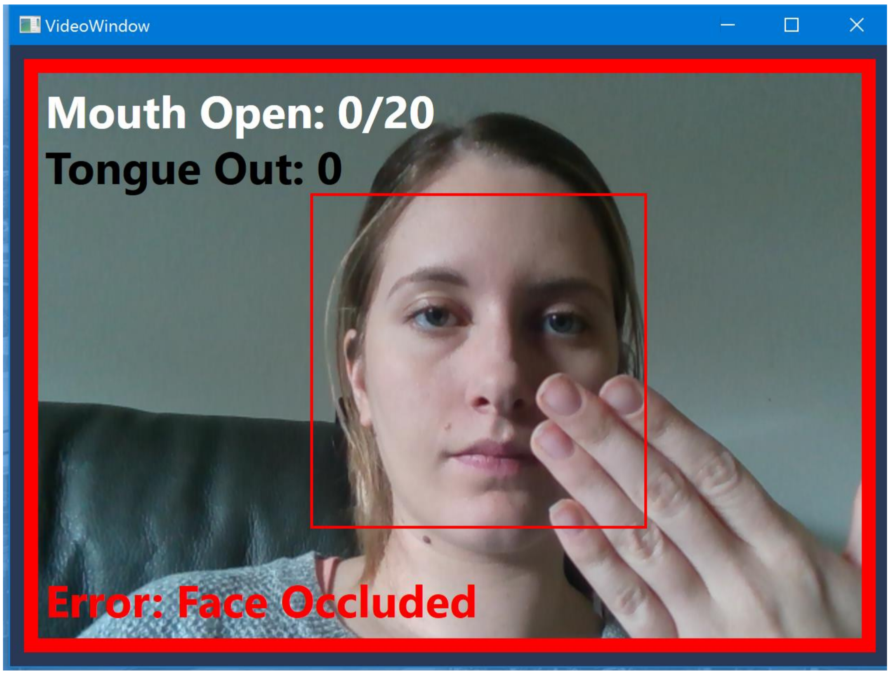

Figure 34: Video window user feedback- face occluded error.

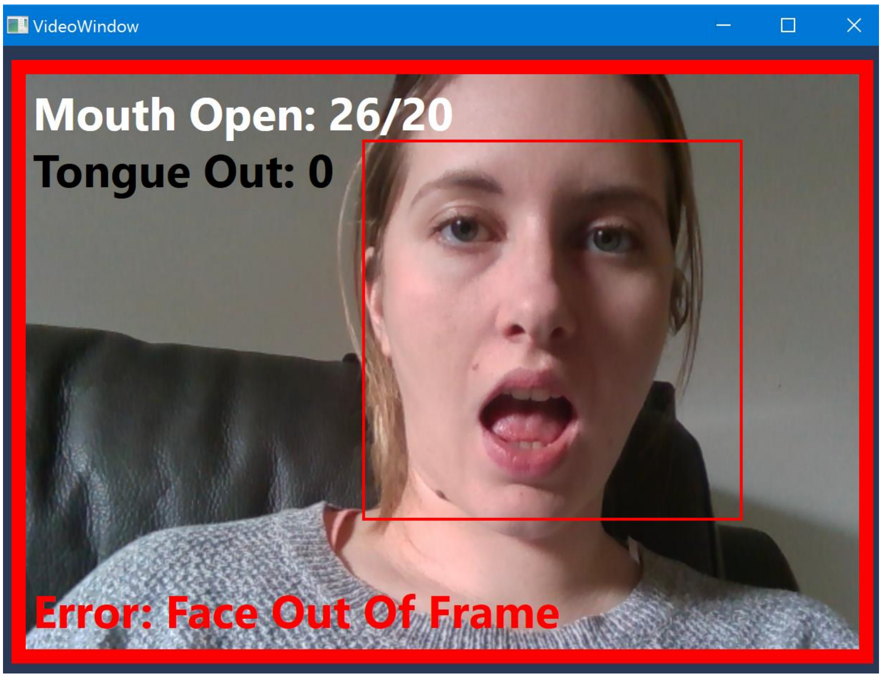

Figure 35: Video window user feedback- face out of frame error.

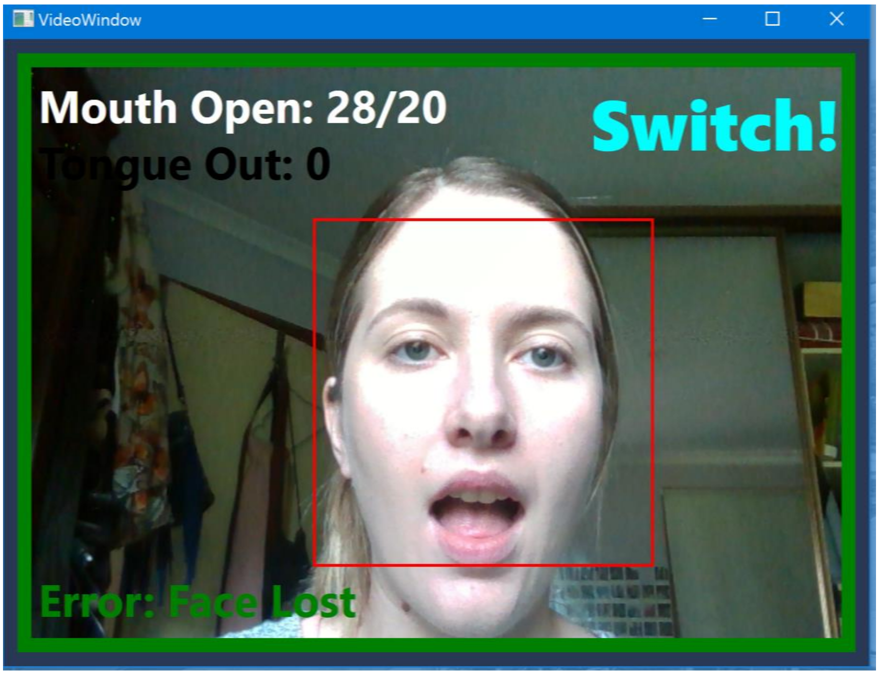

Figure 36: Video window user feedback- face lost error .

4. Methodology

Four end-user participants and six access technology field experts were recruited for this study. The purpose of the pilot trial is to help evaluate the prototype systems clinical application and utility potential, with the feedback being used to improve the system. The pilot trial protocol is shown in Figure 37. Ethics approval letter, information sheets and consent forms can be found in Appendix B.

The study will involve user trials and feedback to the FaceTracker system using two assessment tools:

1. The Novita Switch Access Solutions Assessment (NSASA) form
2. FaceTracker Utility Questionnaire – Appendix D

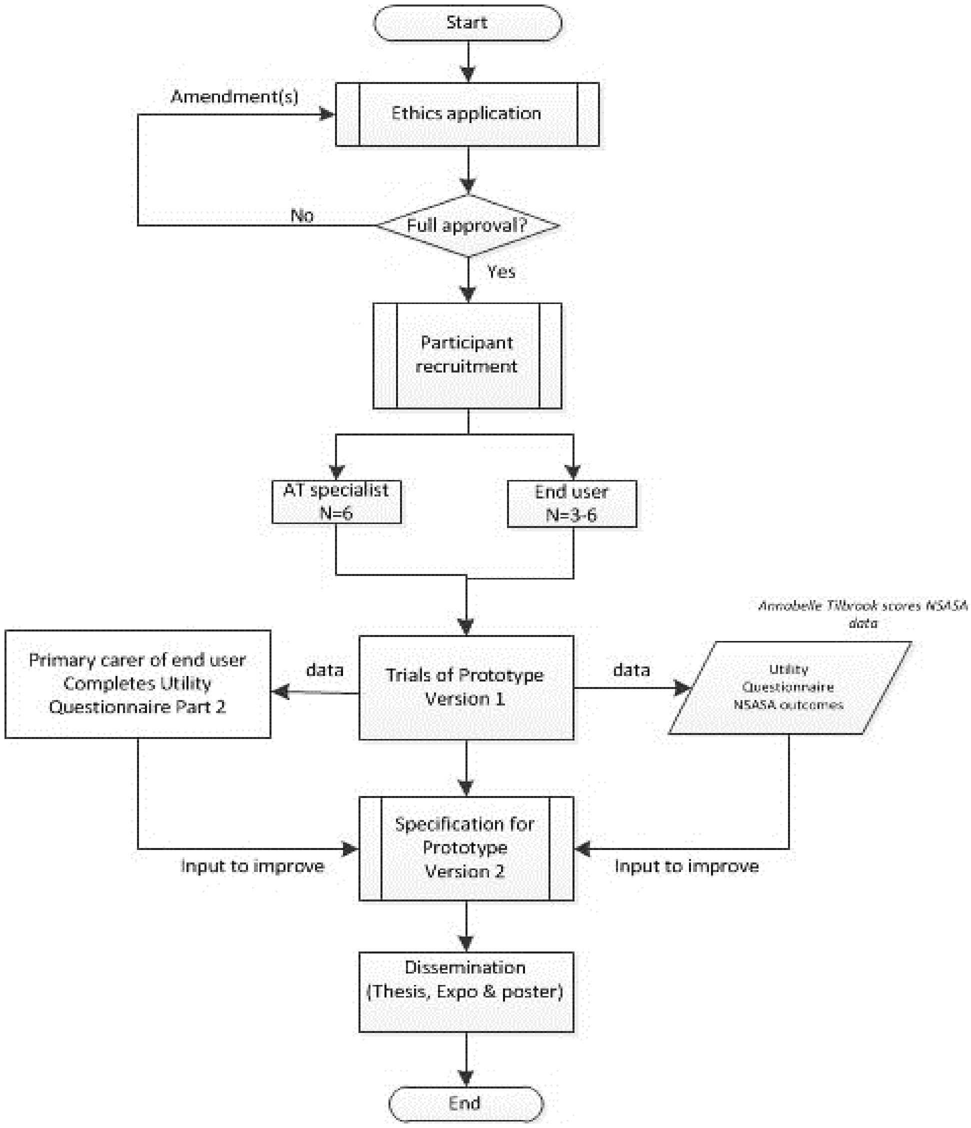

Figure 37: FaceTracker pilot trial protocol flow diagram.

4.1. NSASA

Assessing a client with severe or multiple disabilities for suitability of a switch type is not as straightforward as assessing how fast and accurately they can use the access method. There are a number of areas which need to be considered including: the clients cognitive and motor abilities, their vision level, what activities the client wishes to achieve, which body part is suitable for accessing a switch, which body movements can be made to activate a switch and the suitability of the switches properties to the client's abilities (Tilbrook et al., 2017). Novita developed NSASA to help therapists determine whether a particular switch set-up is an efficient and effective method of access to assistive technology for a client with severe or multiple disabilities (Tilbrook et al., 2017). The tool can be used to compare a client's change in abilities over time, or to compare two different switch set-ups to determine which is most suited to the client. The NSASA form is currently been validated for reliability and clinical utility (HREC/15/WCHN/71) with preliminary results showing strong reliability and validity.

In this trial, the NSASA form will be used to compare the suitability of the FaceTracker switch access solution in comparison to the client's current computer access method. Annabelle Tilbrook – one of the co-developers of NSASA will score the videos for each assessment session with the participants as she has the required training and certification. The score for each access method will be based on their performance in particular motor, visual and process skill areas. The areas examined are listed below, followed by an explanation of the scoring criteria (cannot provide more detailed information due to commercial-in-confidence).

1. **Motor Skills**
    1.1. Fluid movements on approach to switch.
    1.2. Accurately contacts switch.
    1.3. Applies appropriate force to switch
    1.4. Accurately releases switch in controlled and timely manner.
    1.5. Maintains functional position for proper switch activation.
    1.6. Endures to complete activity without obvious fatigue and/or pain.

2. **Visual Skills**
    2.1. Looks at and focuses on visual target.
    2.2. Visually tracks, scans or shifts gaze.

3. **Process Skills**
    3.1. Attends to activity rather than external distractions.
    3.2. Understands purpose/goal and required action to complete activity.
    3.3. Appropriate and safe use of the switch.
    3.4. Starts activity independently.
    3.5. Sequences activity logically without omitting any steps.
    3.6. Responds to cues.
    3.7. Problem solves when errors occur.
    3.8. Ends activity at appropriate time.

Scoring of each skill being completed effectively and efficiently is based on a scale of 0-4.

- 0 being that the skill performance was not observed or could not be performed.
- 1 being that the skill performance was severely limited.
- 2 being that the skill performance was moderately reduced or inconsistent.
- 3 being that there were minimal issues with performance.
- 4 being that good skills were displayed.

This means that each switch set-up is given a score rating out of 64; motor skills rated out of 24, visual skills out of 8 and process skills out of 32.

4.2. Questionnaire

The FaceTracker Utility Questionnaire is based on guidelines of International Standards Organisation (ISO) 9241- 411: 2012 - Ergonomics of human-system interaction – Part 411: evaluation methods for the design of physical input devices (ISO, 2012)

The tool measures the users comfort and satisfaction in using the technology, specific areas evaluated quantitatively on a rating scale of 0 – 7 (with 0 being lowest level of satisfaction and 7 being the highest level of satisfaction) include:

1. How comfortable the amount of force required for activation of switch was.
2. Smoothness of switch during operation.
3. Effort required to operate switch.

4. Level of accuracy of the switch.
5. Whether the operation speed of the switch was acceptable.
6. General level of comfort felt by the user during switch use.
7. Whether the overall operation of the switch was easy or difficult.
8. Level of jaw fatigue experienced during switch use.
9. Level of neck fatigue experienced during switch use.
10. Level of general fatigue (mental/ physical tiredness) experienced during switch use.
11. Level of other fatigue (specified by user) experienced during switch use.

The utility questionnaire also provides qualitative feedback based on the three questions listed below:

1. What do you like/don't you like about the FaceTracker computer access system?
2. Do you have any other suggestions for improvement to the system?
3. Do you think the system would be usable in the environments that you would need to operate it in? Why?

The questionnaire with allow for comparison of trial participants opinions of the system and for further refinement to the system to be made from the user's perspective.

4.3. Access Technology Expert Trial Method

The following protocol was implemented during the access technology expert trials to ascertain the systems usability and elicit feedback to help improve the systems design and implementation. The trial will take approximately 1 hour in duration to complete per participant.

Step #1: Introduction to system (undertaken by Leonie)

- Explain how to:
    - Add new user
    - Change switches/thresholds
    - Show/Hide Video
    - Pause/Start system
    - How to get back into change settings

- Open Grid 3 and discuss:
  - How the user can change settings in Grid 3 to use the two switches for two switch scanning OR single switch scanning with second switch used for executing additional command (e.g. backspace).
  - Explain how Grid 3 can also be set up to have command executed when switch 1 or switch 2 is set up to 'long hold' (e.g. pause for user)

Step #2: Setting of user profile with appropriate thresholds and expressions for therapist (undertaken by Leonie with assistance from Annabelle)

- Ensuring therapist is positioned correctly in front of camera for best possible accuracy.
- Test and adjust settings as required.

Step #3: Free play time for therapist to explore program.

Step #4: Therapists undertake two activities:

1. Open Word and type: "Hello World".
2. Search on google for Novita website and open it.

These activities are firstly undertaken using a single expression for single switch scanning method, following this the two activities repeated and Grid 3 is changed to two-switch scanning input. The therapists are free to choose any two expressions they would like to use.

Step #5: Fill out Utility Questionnaire form.

4.4. Clients Trial Method

The following protocol was implemented during the client trials to determine the users comfort and opinion on system performance from the point of view of a potential end user. The trial will take up to 2 hours to complete, however this can be completed over two sessions if necessary.

Step #1: Set NSASA goal and tasks to complete with client (undertaken by Annabelle)

Step #2: Testing of current computer access method (undertaken by Annabelle)

    - Type ‘Hello World’
    - Client determined task

Step #3: Introduction to system (undertaken by Leonie)

- Explain how to:
    - Add new user
    - Change switches/thresholds
    - Show/Hide Video
    - Pause/Start system
    - How to get back into change settings

- Open Grid 3 and discuss:
    - How the user can change settings in Grid 3 to use the two switches for two switch scanning OR single switch scanning with second switch used for executing additional command (e.g. backspace).
    - Explain how Grid 3 can also be set up to have command executed when switch 1 or switch 2 is set up to ‘long hold’ (e.g. pause for user)

Step #4: Setting of user profile with appropriate thresholds and expressions for client (undertaken by Leonie with assistance from Annabelle)

- Ensuring client is positioned correctly in front of camera for best possible accuracy.
- Test and adjust settings as required.

Step #5: Free play time for client to explore program.

Step #6: Testing of FaceTracker with same tasks as current system (Annabelle)

- Same tasks as Step #2.

Step #7: Caregiver (or Leonie if no other alternative) to fill out feedback forms direct from client feedback.

5. Results and Discussion

This section of the thesis will outline the results achieved from the methods highlighted in Chapter 4 and discuss the meaning of the findings. Firstly, results obtained from trialling the FaceTracker system with the access technology field experts will be discussed – this will give feedback on areas of improvement for the application design as well as the functionality based on their previous experiences with clients and personal opinions. Secondly client results will be discussed – these four clients were recommended by Novita staff for participation in the trial due to their potential to be future end-users of the system. Therefore, their feedback is vital for the success of the system if it were to become commercialised. A comparison will be made between their current switch access system and the FaceTracker switch access system.

5.1. Access Technology Experts – Utility Questionnaire Results - Part #1

During the trial of FaceTracker by the access technology experts, the participants were asked to conduct two activities - using both a single switch and double switch access method. This meant that in total they used three different expressions with one being the mouth open expression. This section of the results shows the ratings of different system performance areas in comparison to the other field experts who trialled the same expression. The mean rating value between testers is also shown with the standard deviation for all expressions except for 'kiss' due to their only being one participant who trialled this expression option.

5.1.1. Mouth Open Expression

Figure 38 and Figure 39 show the large variation between the six participants in their opinion of using the 'mouth open' expression with FaceTracker. The highest levels of variation were experienced in system performance areas of accuracy, effort, neck fatigue and general fatigue. It can be seen that there are similarities with those who rated the force required low on the level of satisfaction, also rated the smoothness, effort required and jaw fatigue as low satisfaction. Neck fatigue received the highest level of satisfaction and also the lowest standard deviation, therefore it was a common agreement that neck fatigue was not an issue.

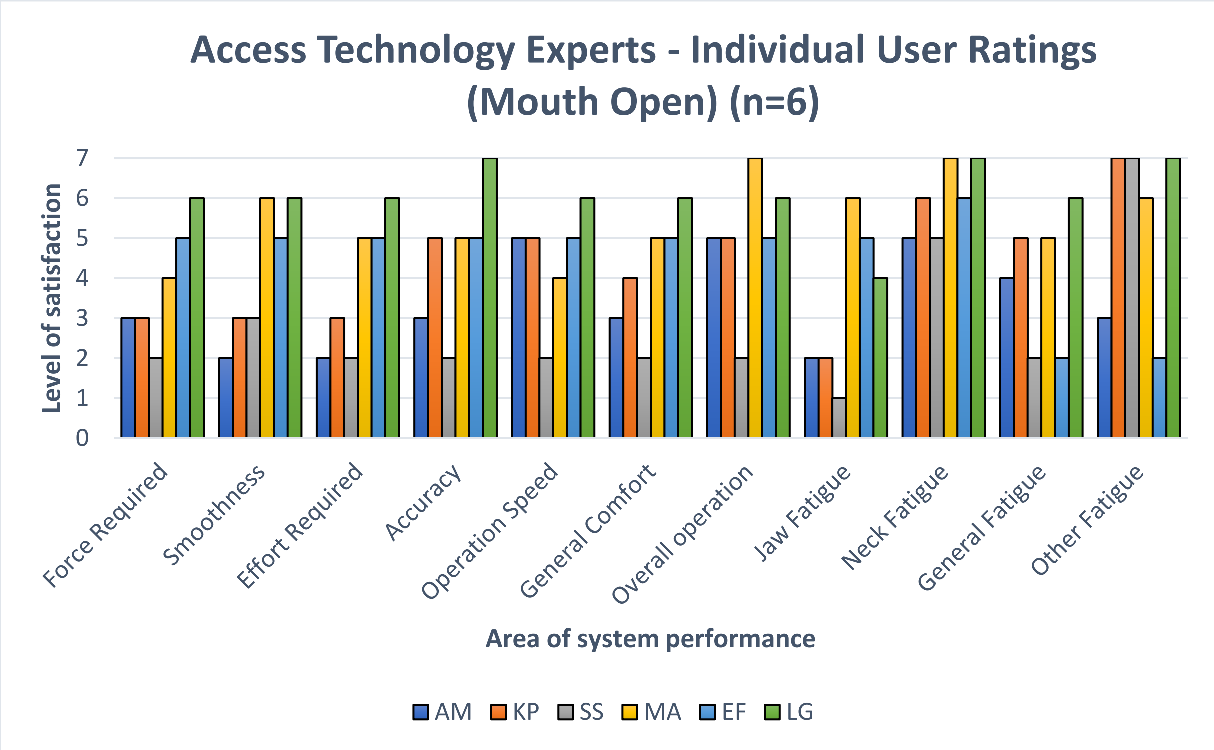

Figure 38: Comparison of individual utility questionnaire results part 1 ratings (mouth open).

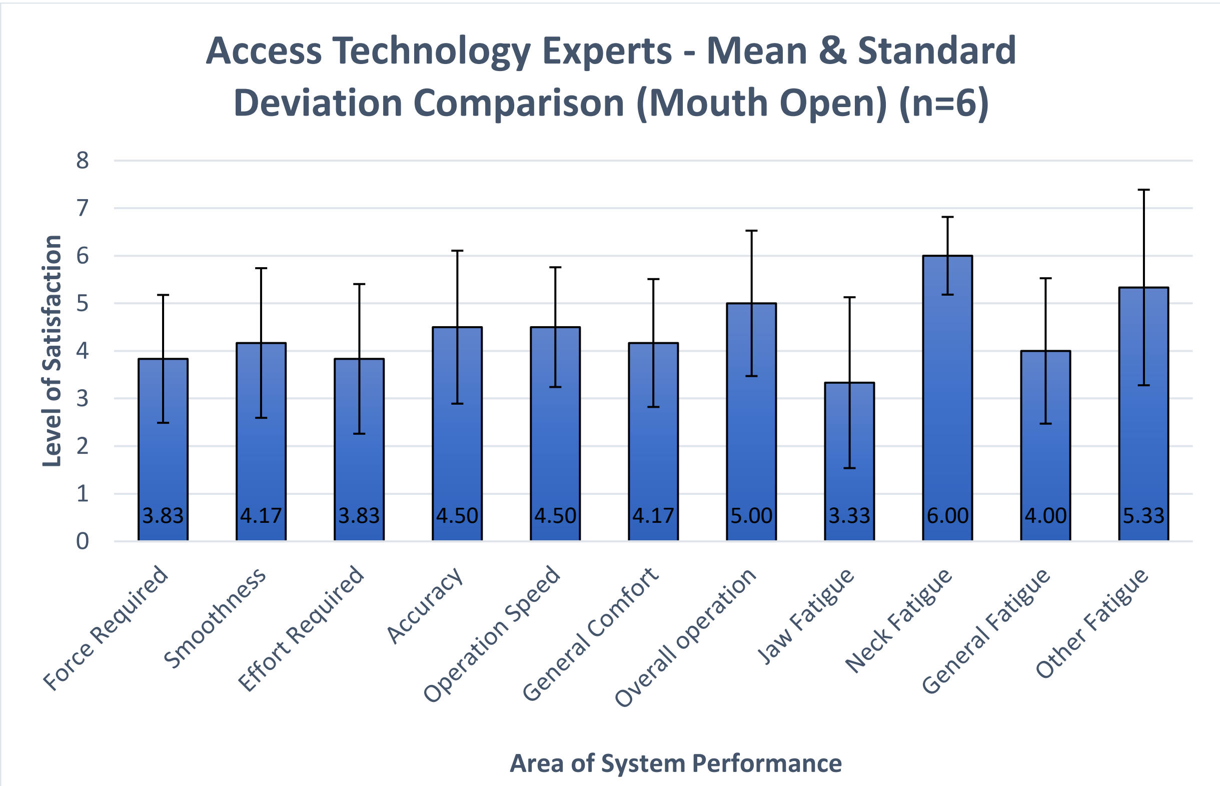

Figure 39: Comparison of mean values for all system performance areas (mouth open).

5.1.2. Eyebrow Raise Expression

Figure 40 and Figure 41 show the variations in the three participants who tested the 'eyebrow raise' expression. One participant found the use of this expression easy and rated all fields at full level of satisfaction. The other two found this expression performed at a good level of satisfaction, however one experienced high levels of general fatigue. The mean values were nearly all above a 5 satisfaction rating. Again, it was agreed that neck fatigue was not an issue.

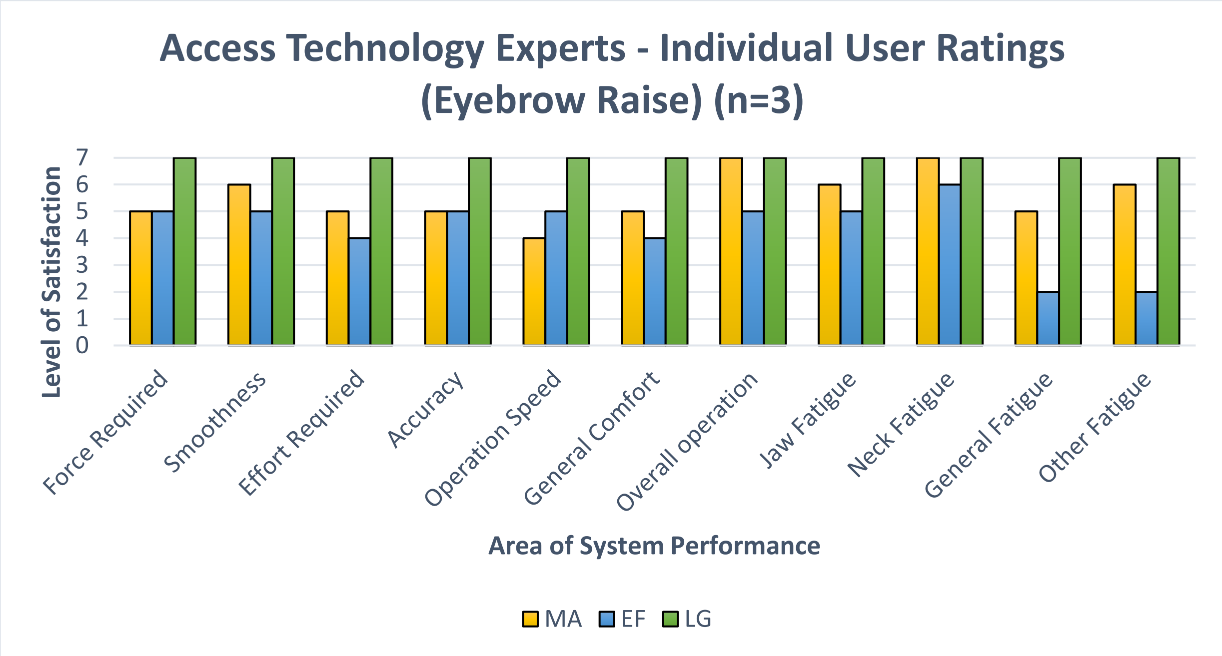

Figure 40: Comparison of individual Utility Questionnaire results part 1 ratings (eyebrow raise).

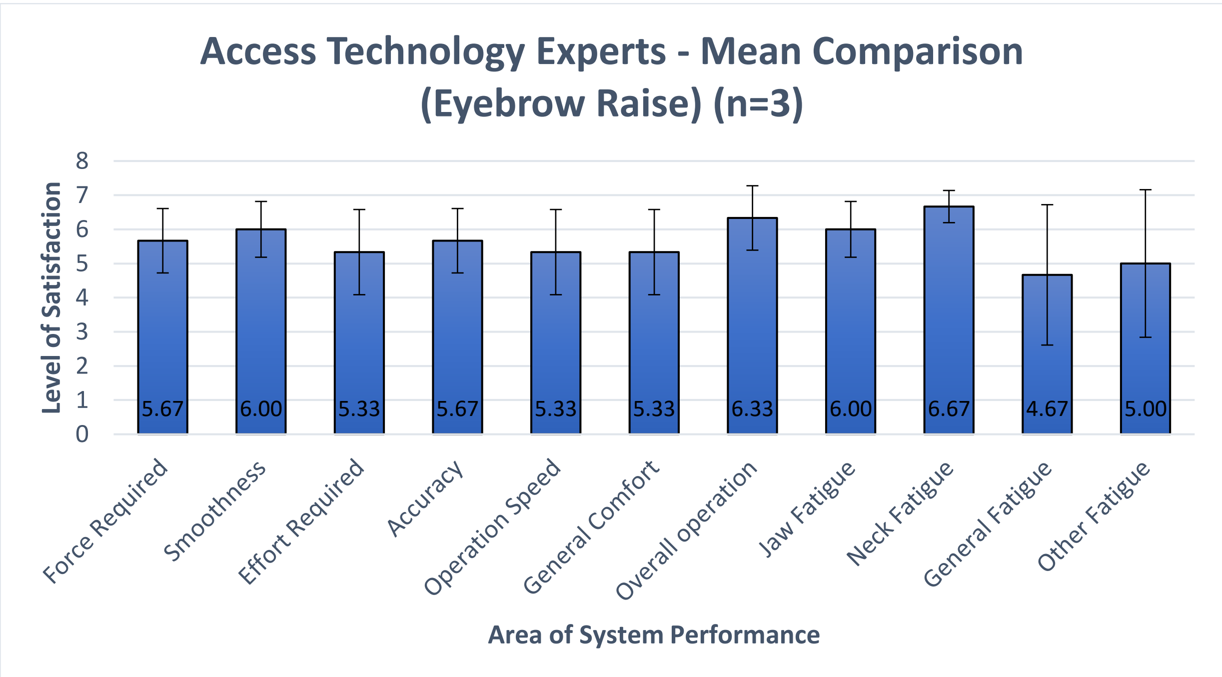

Figure 41: Comparison of mean values for all system performance areas (eyebrow raise).

5.1.3. Puff Cheek Expression

Figure 42 and Figure 43 show the variations in the opinions of the three participants who tested the 'puff cheek' expression. Once again, the means for all system performance areas were above 5 (apart from general fatigue which was 4.33). However, there was a large variation in opinion for each area with a standard deviation greater than one for all performance areas except for neck fatigue once again, which was minimal for all participants.

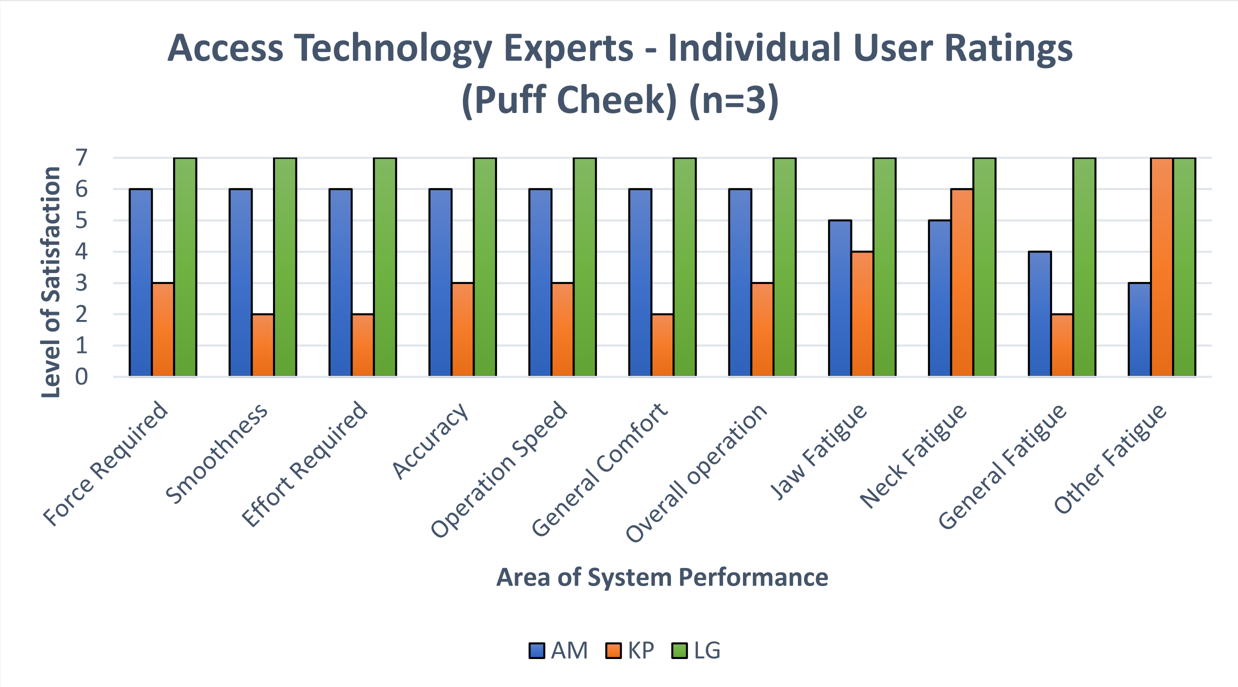

Figure 42: Comparison of individual Utility Questionnaire results part 1 ratings (puff cheek).

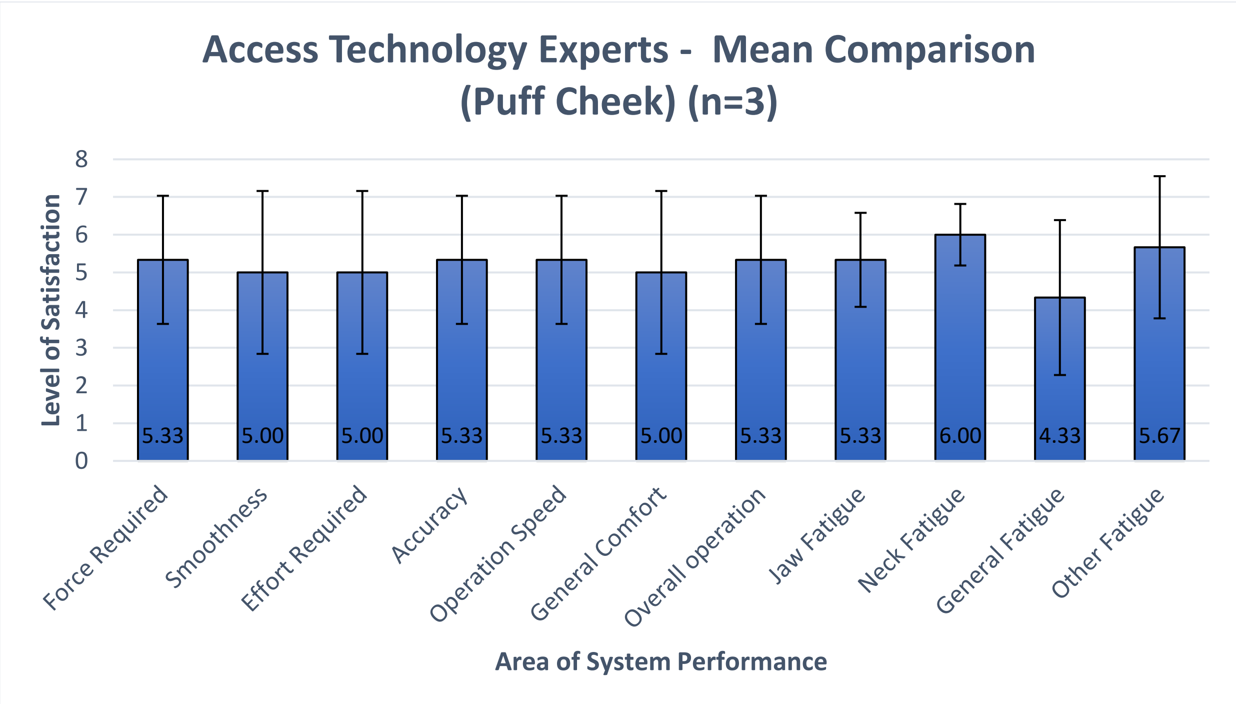

Figure 43: Comparison of mean values for all system performance areas (puff cheek).

5.1.4. Tongue Out Expression

Figure 44 and Figure 45 show the variations in the opinions of the three participants who tested the 'tongue out' expression. The opinions of all participants were fairly similar in this expression with means all being around 4-5 and standard deviations below 1, apart from the areas of smoothness, operation speed and other fatigue. Neck fatigue was once again the highest level of satisfaction ranking with lowest standard deviation.

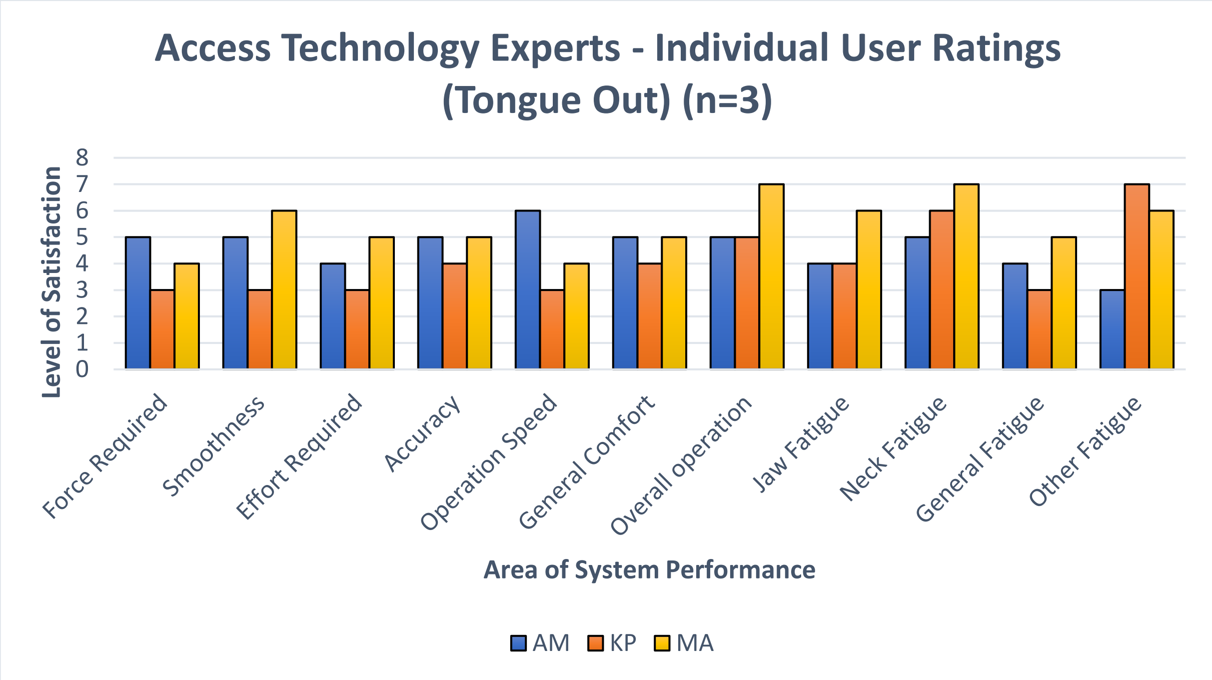

Figure 44: Comparison of individual Utility Questionnaire results part 1 ratings (tongue out).

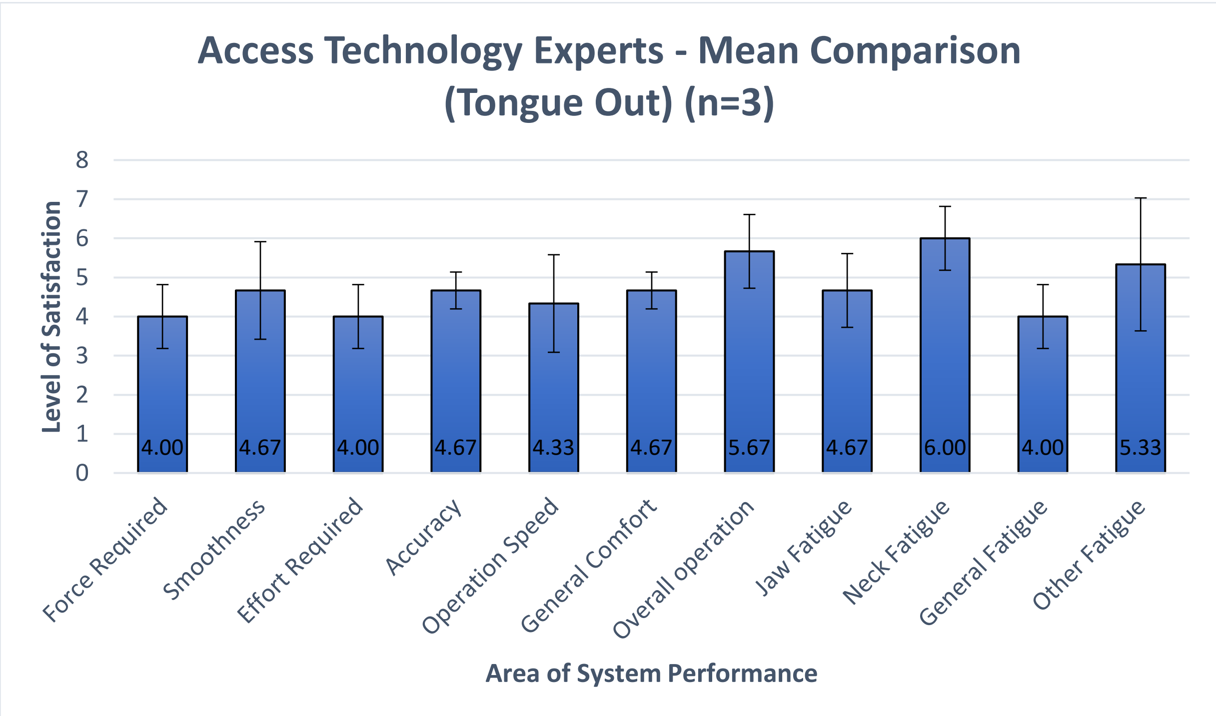

Figure 45: Comparison of mean values for all system performance areas (tongue out).

5.1.5. Smile Expression

Figure 46 and Figure 47 show the variations in the opinions of the two participants who tested the 'smile' expression. One user found the smile expression a very good option with high rankings in all areas of system performance. The other user found it a little bit more effort with lower rankings in all areas, although levels of fatigue were not high for either participant. All mean levels were above 5 although the sample number was only n=2.

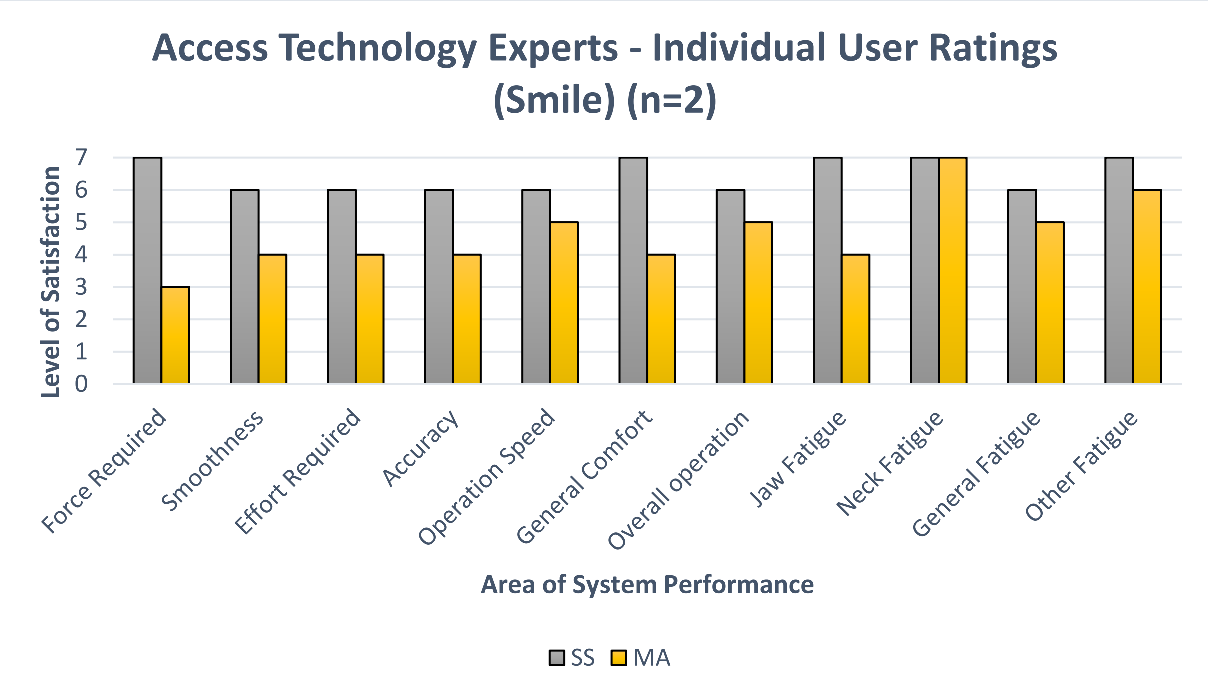

Figure 46: Comparison of individual Utility Questionnaire results part 1 ratings (smile)

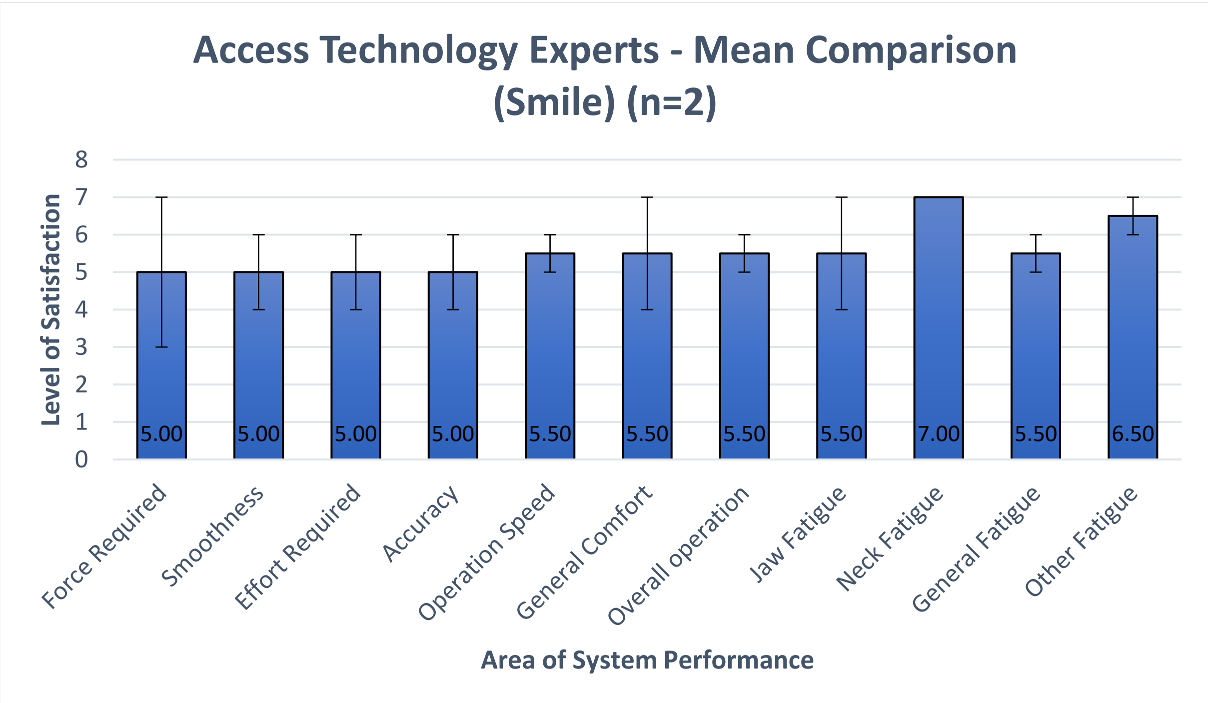

Figure 47: Comparison of mean values for all system performance areas (smile)

5.1.6. Kiss Expression

Figure 48 shows the opinion of the participant who tested the 'kiss' expression for each area of system performance of the utility questionnaire. This participant found the effort and fatigue levels for this expression was very good, however the smoothness, accuracy, operation speed, overall operation and general fatigue were rated at a 4.

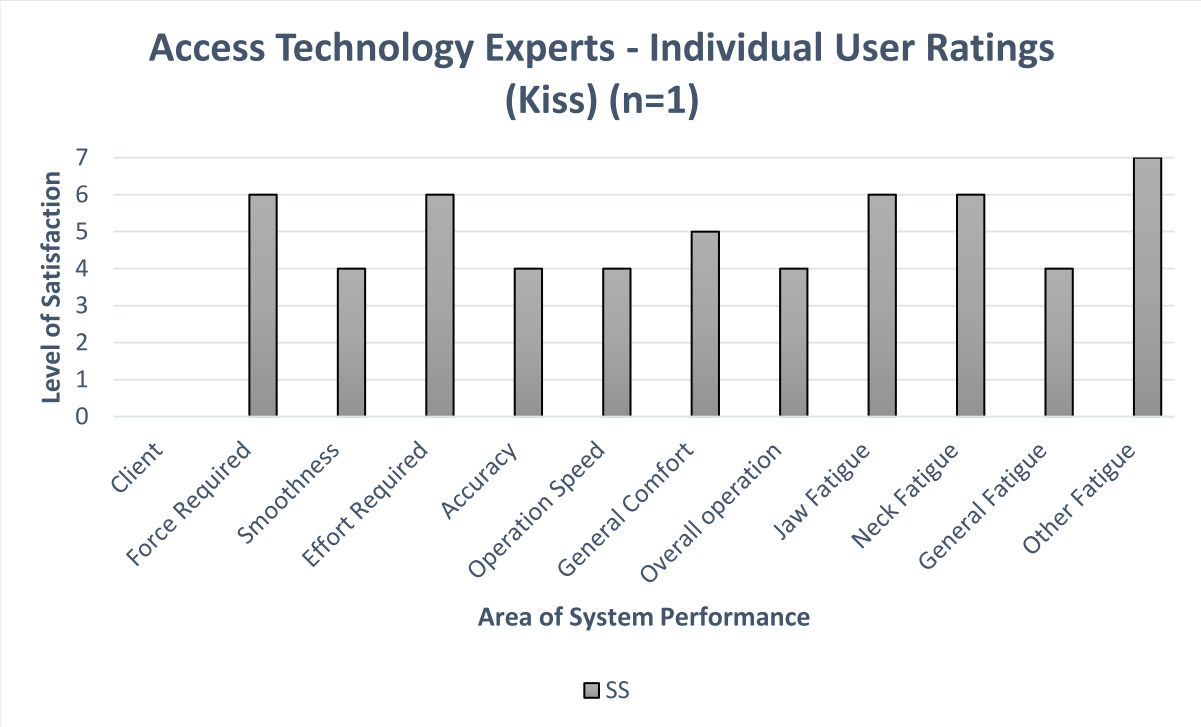

Figure 48: Comparison of individual Utility Questionnaire results part 1 ratings (kiss).

5.2. Access Technology Experts – Utility Questionnaire Results - Part #2

The access technology experts also filled out three qualitative questions to give further feedback on areas of the system that they liked and didn't like, their ideas for improvements and their opinion on whether they think the system would be suitable in the environments their clients would need to use them in.

Table 6, Table 7 and Table 8 show the categorised comment topics from each question and the number of field expert trial participants who made a comment about that topic.

Table 6: Access technology experts Utility Questionnaire part 2 results qualitative feedback - Question 1

Question 1: What do you like/don't you like about the FaceTracker computer access system?	
Feedback Categories	**Number of Comments**
Easy to set-up (test different expressions and adjust sensitivity) and intuitive to use.	4
Tolerance to face movement and ability to have variable distance from camera is good.	3
Ability to still talk while using the system is good	2
Not affected by noise and doesn't require user to make noise.	1
Less fatiguing than eyegaze systems.	1
The user can adjust the settings themselves.	1
Eyebrows expression was false activating.	1
Difficult to use as a two-switch system – might be good with one facial expression integrated with an alternate switch.	1
Quite fatiguing and mentally draining (but assume would get easier with time and practice).	1

Table 7: Access technology experts Utility Questionnaire part 2 results qualitative feedback - Question 2

Question #2: Do you have any other suggestions for improvement to the system?	
Feedback Categories	**Number of Comments**
Way for user to pause the camera and make it more obvious system is paused.	3
More information provided to user about required movements, ability to display video and how to fix errors.	3
Create a specific Grid 3 page for easier access to FaceTracker settings.	3
Would be good if FaceTracker could be used in combination with other systems such as Eyegaze or head pointer mouse.	1
More commercial GUI appearance.	1
Ability to toggle FaceTracker over Grid 3 set or dock apart.	1
Greater ability to calibrate movement / amount of movement needed.	1
Another expression option – long blink.	1

Table 8: Access technology experts Utility Questionnaire part 1 results qualitative feedback - Question 3

Question #3: Do you think the system would be useable in the environments that you would need to operate it in? Why?	
Feedback Categories	**Number of Comments**
Yes, as it is not affected by background noise - it could be used in home environment as well as noisy environment such as school.	3
Could be some issues with glare and outdoor use – needs to be tested.	3
Yes, copes with large amount of movement.	1
Yes, but could have some difficulties for those with severe dystonic movements.	1

5.2.1. Summary

The feedback from the access technology experts showed that preference for particular facial expression usage varied greatly between the small sample size. This is a major advantage of FaceTracker as it incorporates options for a range of facial options to be used, enabling the system to accommodate a variety of users. The main areas of feedback from the participants included that they liked the ease of use of the application and its ability to continue to detect while talking and moving about. They also liked that the user was able to adjust the settings of the application themselves. Dislikes included the accidental activations – this was particularly for the kiss and eyebrow expressions as they were quite sensitive to movement. This may be partially due to different face appearances – but this could also be improved so that detection is only enabled when the user is facing the screen for these expressions. Some users also found that it was difficult to use two different expressions for two switch scanning but that it may be useful with an alternate switch. Finally, some found the system quite fatiguing but they were not used to using the switch scanning process, so that would have played a part in their fatigue and would likely get easier with time.

The main areas of suggested improvement included:

- Making it more obvious that the system is paused and that there is the option to show video feedback.
- Integrating FaceTracker with a specialised Grid 3 set so that users can interact with the application easier.
- Docking of the application so that Grid 3 does not cover the application and make it difficult to interact with.
- Further information on the exact expression that needs to be performed – picture or video.

The participants thought that the system would be suitable for indoor environments but believed that further testing would be required to determine If glare and bright light would impact on the reliability of the system.

5.3. Client Results - Overview

During the trial of FaceTracker by the clients who represent potential end-users of the system, the participants were asked to conduct two activities based on their personal access goals. The tasks were completed on both the clients current switching system as well as the FaceTracker system for comparison. One task was attempted to be kept constant between all clients – type 'hello world' however due to misunderstanding or wanting to do an alternate activity this was not successfully achieved. Client RE completed the 'hello world' task both for her current system and FaceTracker system trial, Client EK completed the 'hello world' task only once for the FaceTracker trial but completed a 'search for a website' task on both systems. Finally, client JA completed the similar task of 'typing an SMS (3 words)' on both systems. Although unable to compare between clients, the similar tasks enabled a level comparison between the client's current system and the FaceTracker system. The utility questionnaire feedback was provided by clients verbally and notated by the author with a therapist also present for the adult clients who did not have a caregiver present.

5.3.1. NSASA Results

Figure 49 shows the NSASA results for each client's current switch access method and the FaceTracker access method. Clients EK and JA had a +3 difference in favour of the FaceTracker system, meaning that their performance was better using the FaceTracker system than their current system. Client RE had a difference of -1 meaning that their existing system was marginally better than FaceTracker for them, however this may be as a result of greater familiarity.

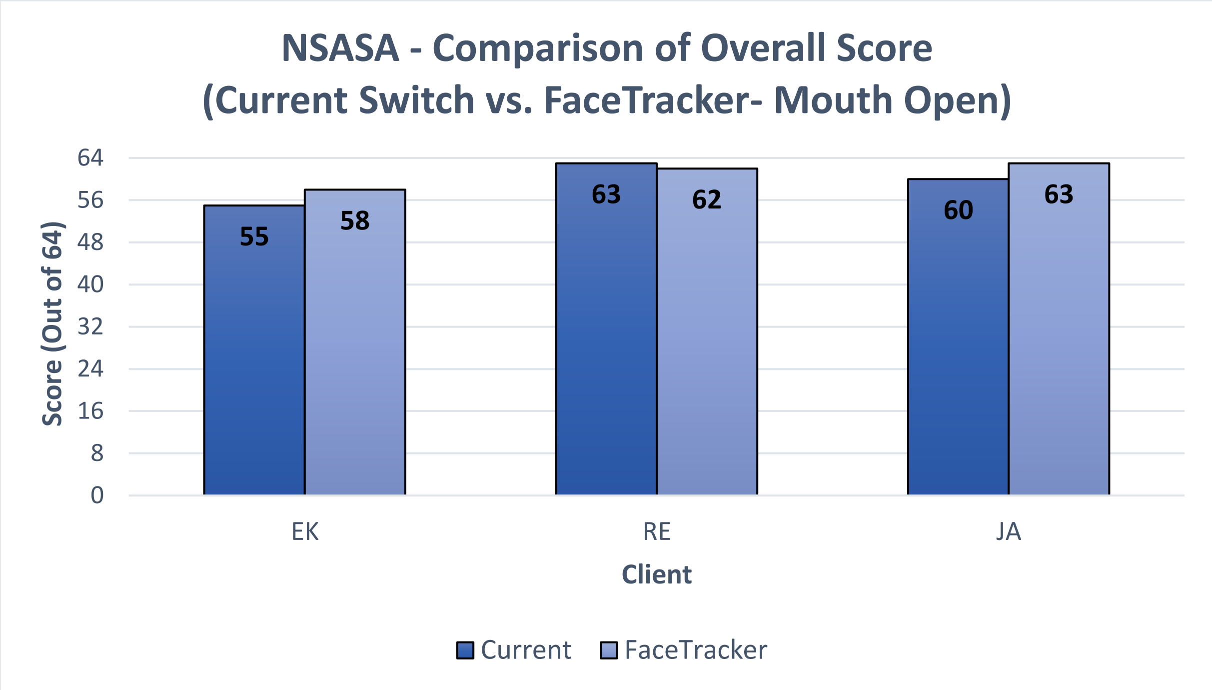

Figure 49: Comparison of overall NSASA scores for all end-users.

Figure 50 shows the score percentages achieved by each client for their performance in the NSASA areas of motor, visual and process skills for their current system and the FaceTracker system. It can be seen that all clients received maximum scores for both visual and processing skill score areas, therefore it was motor skill areas where differences occurred and these variations can be seen in Figure 51.

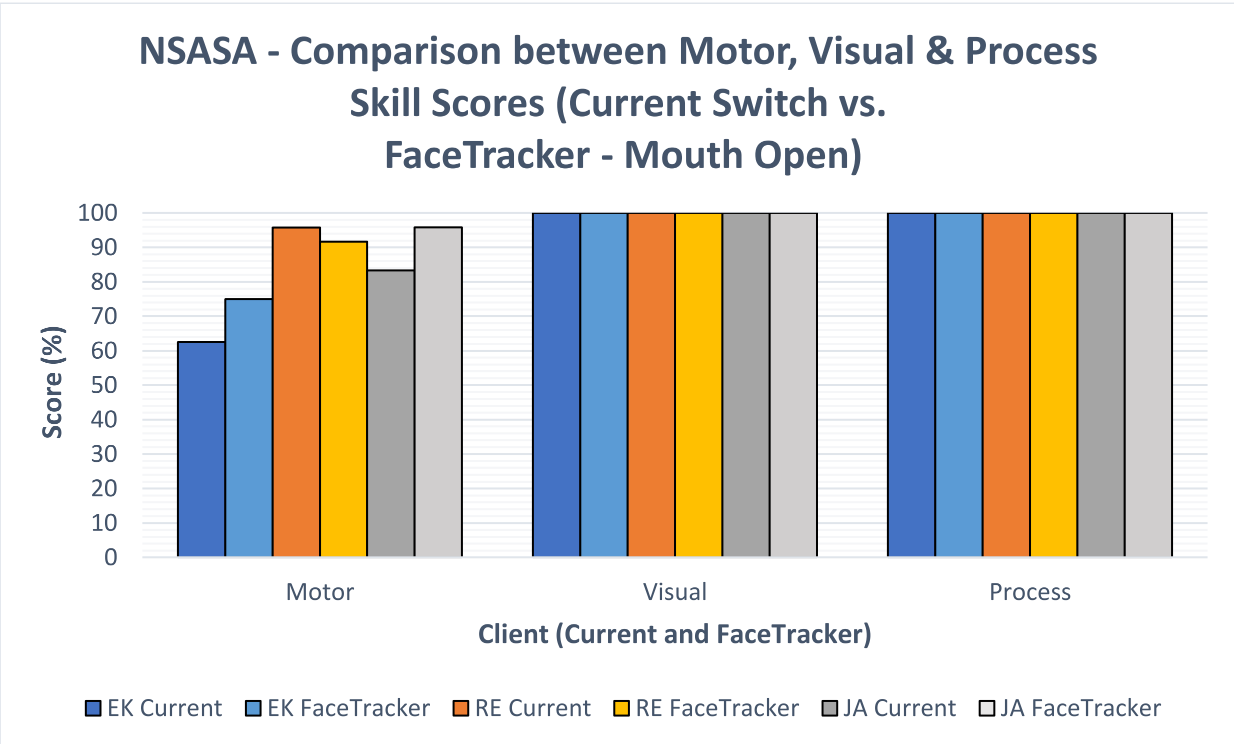

Figure 50: Comparison of NSASA individual motor, visual and process scores for all end-users.

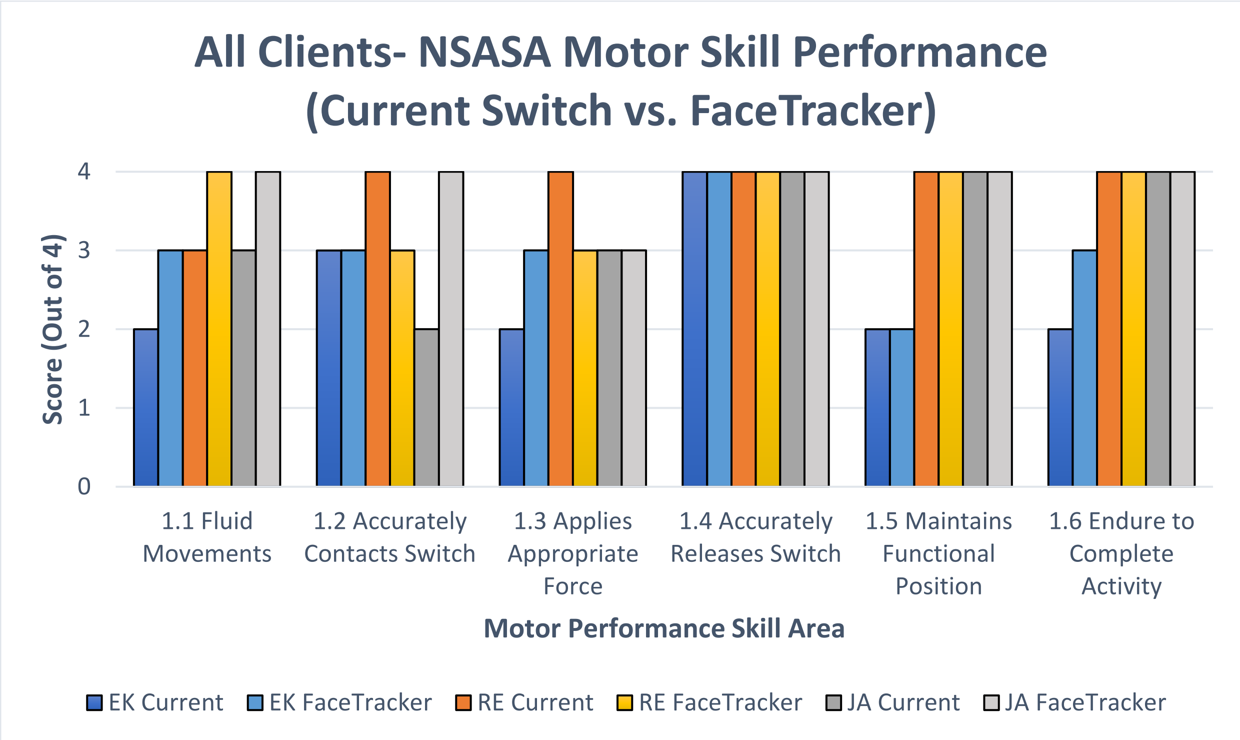

Figure 51: Comparison of NSASA motor skill areas for all end-users.

Feedback given from part 1 of the utility questionnaire for all the clients is shown in Figure 52 with the mean values and standard deviations shown in Figure 53.

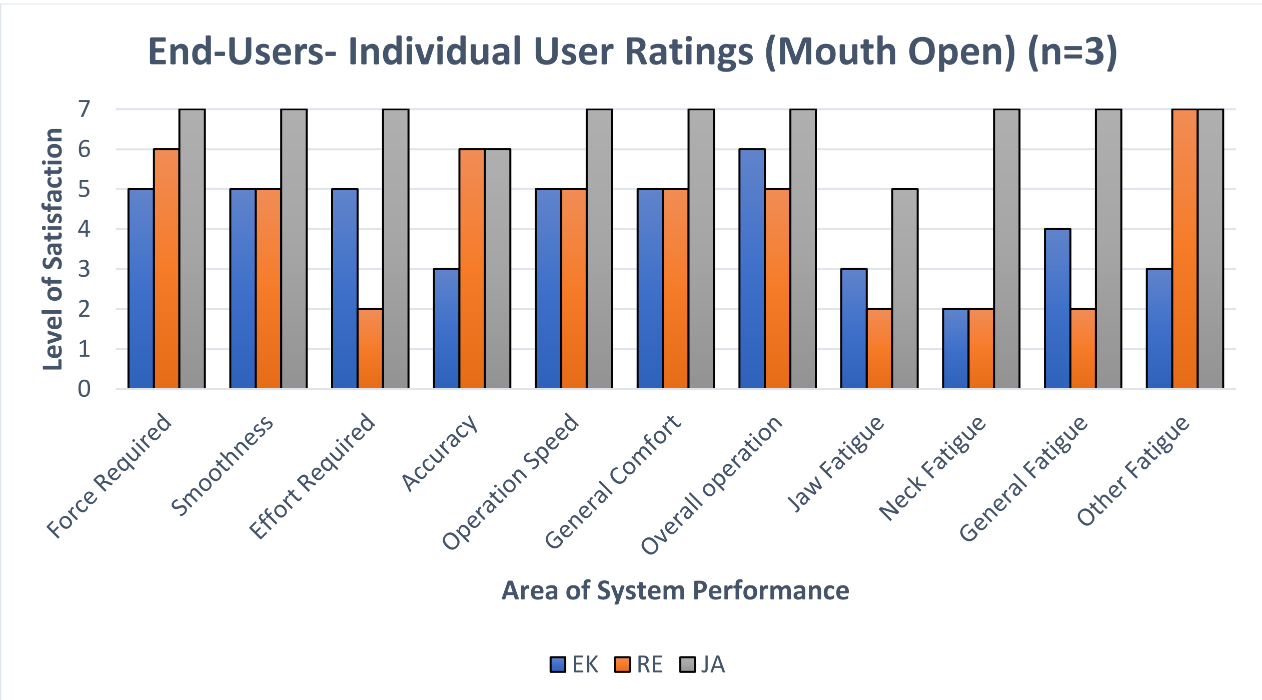

Figure 52: Part 1 Utility Questionnaire results for all end-user trials.

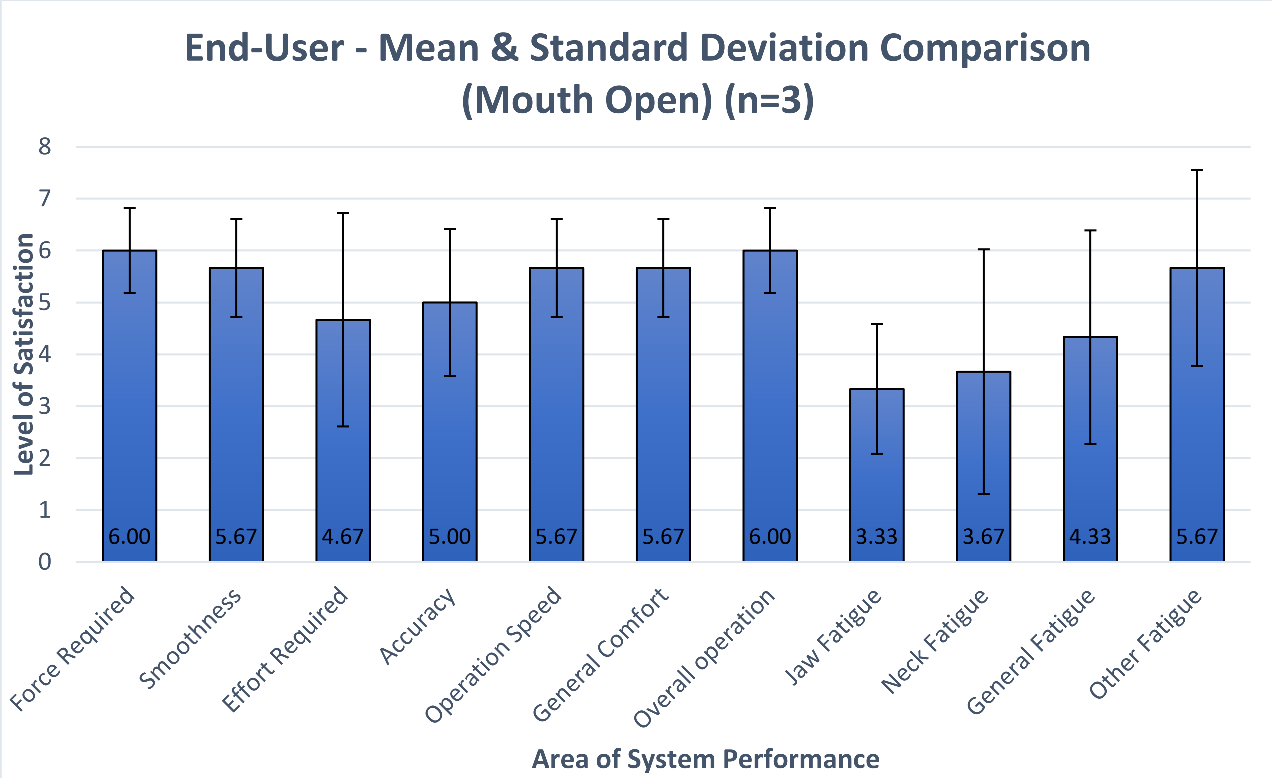

Figure 53: Utility Questionnaire Part 1 - system performance areas mean comparison.

These graphs show that there is a large variation between user ratings of system performance. This is due to the clients having different diagnosis, needs and testing environments. Therefore, a case by case results review will be undertaken in the following sections 5.4-5.7.

5.4. Client Case #1 – EK

EK is a 15-year-old male with mixed dyskinetic cerebral palsy and is the motivation behind this project as described in section 1.2. He currently uses a sound switch as his access method and it is hoped that FaceTracker will provide him with a more effective access method which is more socially acceptable, less fatiguing and more reliable. Figure 54 shows EK using the FaceTracker system during his trial.

Figure 54: Client EK testing the developed FaceTracker computer access system.

5.4.1. Comparison between current and developed system (NSASA results)

During the pilot trial, EK completed the following tasks for NSASA assessment via single switch scanning using a Grid 3 computer access grid set:

Current Access Method (Sound Switch):

1. Navigate windows to open wanted website.
2. Shut down computer.

FaceTracker:

1. Navigate windows to open wanted website.
2. Type 'Hello World'.

As shown in Figure 49 and Figure 50, EK's NSASA scores were: 55/64 for his current switch system and 58/64 for the FaceTracker switch system. This gives a +3 score difference showing that the FaceTracker system could potentially be a better solution for EK.

As discussed in section 5.3, all clients scored full marks for both visual and processing skills in the NSASA assessment - Figure 55 shows the differences in EK's motor skill performances for use of the sound switch and the FaceTracker system. This graph shows that EK's performance with the FaceTracker system showed improvements in comparison to his current system in areas of fluid movement, appropriate force and the ability to endure to complete the activity.

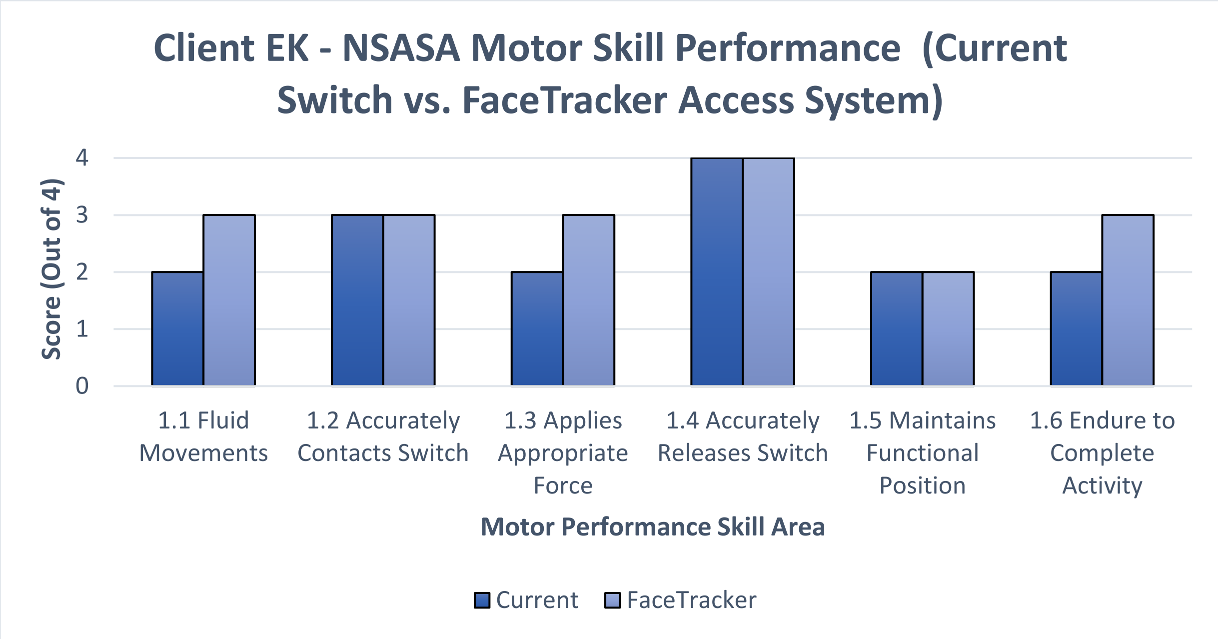

Figure 55: Motor skill performance scores for client EK.

5.4.2. Questionnaire Feedback

Feedback on user comfort and system performance was provided by EK's mother on behalf of EK in part one of the utility questionnaire and is shown in Figure 56. These results show that EK has lower satisfaction levels with accuracy due to reliability of the system and fatigue related issues.

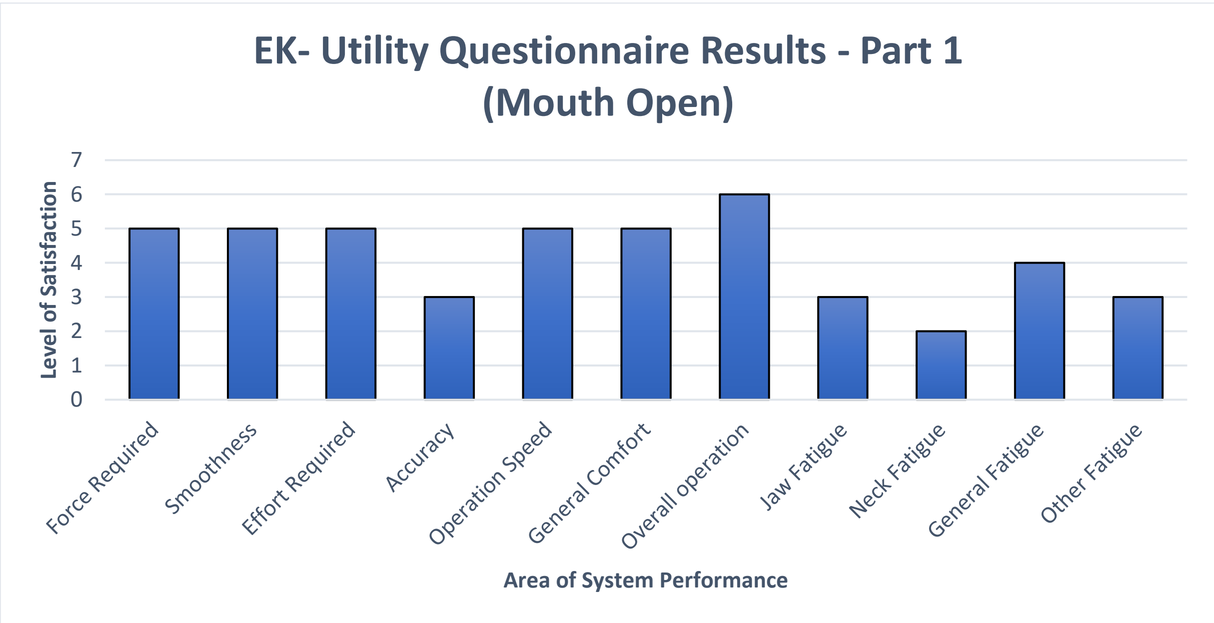

Figure 56: Utility Questionnaire Part 1 individual results for client EK.

Additional, qualitative feedback in part two of the utility questionnaire was also provided by EK's mother, her comments for each question on behalf of EK are listed below:

Question 1: What do you like or don't you like about the FaceTracker computer access method?

- *I love it because it's so quiet compared to the voice switch.*
- *Less effortful than current switch access of voice switch, however currently less reliable in consistently activating.*
- *If issues with glare is resolved, ability to use in range of settings is enhanced versus the voice switch.*
- *Not being able to utilise with current tablet is an issue – this could considerably set back access time waiting for funding.*
- *Need to have EK in a very specific position during trial which could potentially cause fatigue issues in trying to maintain that position (head to side and arms restrained).*
- *Haven't yet been able to determine EK's ability to talk while using the system as only trialled twice.*

Question 2: Do you have any other suggestions for improvement to the system?

- *Haven't trialled enough times to ascertain any other issues than glare and it being inconsistent with picking up EK.*

Question 3: Do you think it would be useable in the environments that you would need to operate it in? Why?

- *If issues with glare and reliability of use are resolved then yes- for home use and school environment as current switch option is a voice switch which can't be used in noisy environments.*

5.4.3. Summary

EK's trial was undertaken in an Assistive Technology Service clinic room at Novita Children's Services. This room had many bright downlights pointing in various directions which seemed to sometimes affect the cameras ability to reliably detect EK's intended switch activations. Due to EK's dystonic movement his change in head position meant that sometimes he was being effectively detected and at other angles no expression was detected at all. There were no issues with glare when the system was first tested in EK's home so it is likely the lighting situation during the trial played a large role in the effectiveness of the system. However, it is important for EK to be able to use the system in various environments so this highlights the need for further investigation into the ability for the system to work in different lighting conditions and whether there is a way to work around the effect lighting has on the systems reliability. EK had recently had spinal fusion surgery. On report and observation this had impacted on the distribution of his tone with a new patterning of involuntary strong rotation of his head to the right. At times, this included his chin contacting his clothing on his right shoulder. This may have also impacted on the camera tracking his face effectively. A big positive that was noted during this trial was the cameras ability to keep up with EK's dystonic movement and not freeze or lag and as a result all activities could be completed – which is a large improvement over his last trial session. The tablet and camera did however have to be positioned at a 90-degree angle to EK during the trial due to his positioning. It is believed that a mounting system to provide the camera with more angle and/or height adjustment would benefit EK and his use of the FaceTracker system largely.

5.5. Client Case #2 – RE

Client RE is an adult Novita client with Multiple Sclerosis who currently uses a direct access method for internet access, social media interaction and environmental control. After a recent review by her occupational therapist it was identified that she will now need to change to a switch access method due to deterioration in her fine motor hand skills. As these skills will continue to deteriorate over time, it was determined that FaceTracker might be a potential future solution. RE has a high level of cognitive skill and during the review she demonstrated the ability to use a mechanical switch effectively, and therefore this will be used as her current switch method for purposes of comparison with the FaceTracker system (as shown in Figure 57).

Image removed due to confidentiality.

Figure 57: Client RE using her current switch access method - single mechanical switch.

5.5.1. Comparison between current and developed system (NSASA results)

During the pilot trial, RE completed the following tasks for NSASA assessment via single switch scanning using Grid 3's Fast Talker Application:

Current Access Method (Mechanical Switch):

1. Type "Hello World".
2. Use Grid 3 calculator to solve multiplication problem (7x6=?)

FaceTracker:

1. Type "Hello World".
2. Use Grid 3 calculator to solve multiplication problem (7x6=?)

As shown in Figure 49 and Figure 50, RE's NSASA scores were: 63/64 for her current switch system and 62/64 for the FaceTracker switch system. This gives a -1 score difference showing that RE performed similarly with both systems, with her current system scoring just slightly better.

As discussed in section 5.3, all clients had no room for improvement for both visual and processing skills in the NSASA assessment - Figure 58 shows the differences in RE's motor skill performances for single-switch mechanical switching and the FaceTracker system. This graph shows that RE had lower performances in skill of accurately contacting and applying the appropriate force for the FaceTracker system. In comparison, she only had a slight issue with the fluid movement of hitting the mechanical switch of her current system.

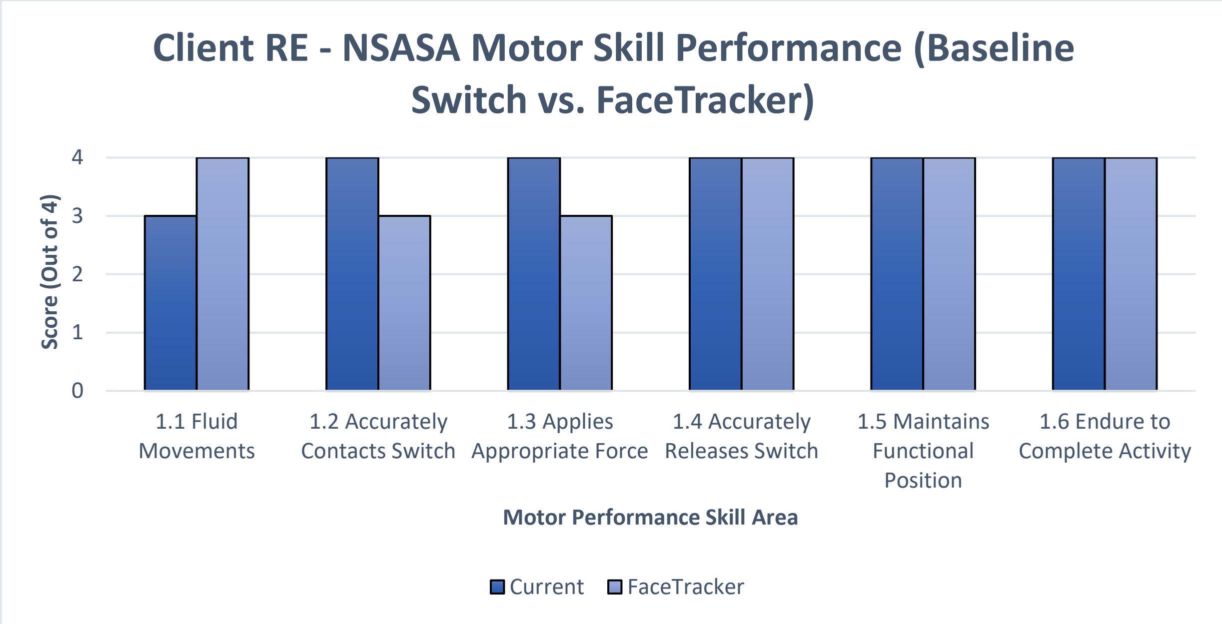

Figure 58: Motor skill performance scores for client RE.

Figure 59 shows RE successfully activating the FaceTracker switch during the trial. Due to detection issues the level of force being used is slightly more than needed.

Image removed due to confidentiality.

Figure 59: Client RE using the FaceTracker system during the trial.

5.5.2. Questionnaire Feedback.

Feedback on user comfort and system performance provided by RE in part one of the utility questionnaire is shown in Figure 60. These ratings highlight that RE experienced high levels of jaw, neck and general fatigue and found that the system took a large amount of effort to use. Her level of fatigue may be as a result of her positioning during testing as shown in Figure 59.

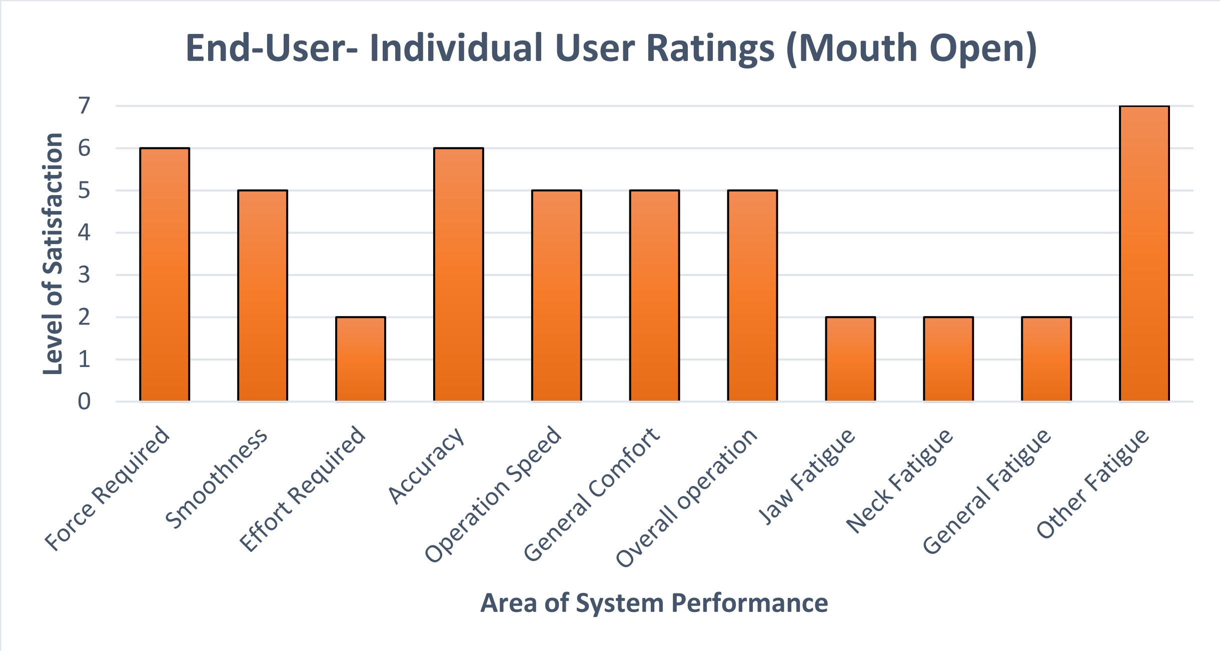

Figure 60: Utility Questionnaire Part 1 individual results for client RE.

In addition to this, RE also provided qualitative feedback in part two of the utility questionnaire, her comments for each question are listed below:

Question 1: What do you like or don't you like about the FaceTracker computer access method?

- *Liked that it was easily explained*
- *Don't like that it isn't able to run on apple products.*
- *Also caused fatigue after not doing all that much (both physically and mentally).*

Question 2: Do you have any other suggestions for improvement to the system?

- *Placement of activating feature not being so sensitive.*

Question 3: Do you think it would be useable in the environments that you would need to operate it in? Why?

- *Reflection and light causing issues and lost face.*
- *Wouldn't use outside unless under shade but around house want it to work anywhere (except where there is extreme light as wouldn't be able to read computer screen anyway)*

5.5.3. Summary

During RE's trial of FaceTracker, it took some time before an appropriate area of her house was found so that the system would work without too many inconsistencies in switch detection. The inconsistencies were likely due to the number of windows with light shining in and causing shadows, as well as the number of reflective surfaces (picture frames, television screens etc.) present in the environment causing glare/reflection back into the camera. This is highlighted in RE's feedback in the questionnaire – she experienced high levels of fatigue due to the amount of times errors occurred and the effort she had to use trying to get the system to work consistently. In addition to this, she also did not like the 'mouth open' expression and suggested she would prefer something more natural and less fatiguing such as a long blink option. If the interference from glare could be reduced/removed, it is likely that this system could be a potential access option for RE but, if not, then it would not be suitable. Another area of feedback was that the system would not work on Apple products which she has a large preference for over Windows. This highlights the need for an eventual cross-platform application if the system were to become commercialised.

5.6. Client Case #3 – JA

JA is a client with Multiple Sclerosis, he is currently using direct access to his Tellus 5 device with Grid 3 software for environmental control and phone access. However, as JA's fine motor skills are continuing to deteriorate he will soon need to swap to a switch access method and had already trialled two-switch scanning with 'jelly bean' style mechanical switches before this trial (shown in Figure 61). He has some difficulties in accurately hitting the mechanical switches and therefore it was determined that FaceTracker could be a potential alternative access solution for JA in the future.

Figure 61: JA using current switch access method.

5.6.1. Comparison between current and developed system (NSASA results)

During the pilot trial, JA completed the following tasks for NSASA assessment via double switch (current method) and single switch (FaceTracker) scanning using the Grid 3 Computer Application Grid Set:

Current Access Method (Mechanical Switches):

1. Type SMS (3 words) 'How are you'.
2. Play game: Connect 4.

FaceTracker:

1. Type SMS (3 words) 'Are you well'
2. Play game: Maze.

As shown in Figure 49 and Figure 50, JA's NSASA scores were: 60/64 for his current switch system and 63/64 for the FaceTracker switch system. This gives a +3-score difference in favour of FaceTracker being a more effective access solution for JA. However, as it is not a large difference both systems are similar in levels of effectiveness currently.

As discussed in section 5.3, all clients had maximum scores for both visual and processing skills in the NSASA assessment - Figure 62 shows the differences in JA's motor skill performances for two-switch mechanical switching and the FaceTracker system. This graph shows that JA had trouble in accurately contacting the mechanical switches and sometimes did not apply the appropriate force to activate them. Similarly, it can be seen that the area that JA could improve on with the FaceTracker system is also the force in which he uses to activate the system.

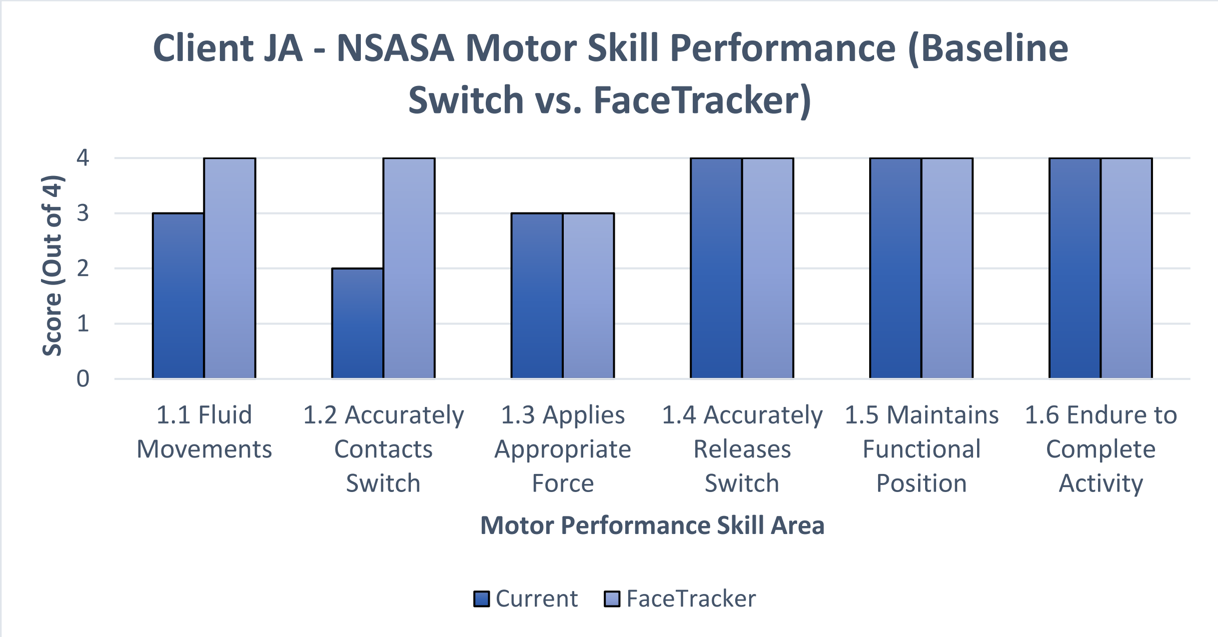

Figure 62: Motor skill performance scores for Client JA.

Figure 63 shows the slightly exaggerated level of force JA was applying to activate the FaceTracker switch during the trial. This is more than required and may cause quicker fatigue.

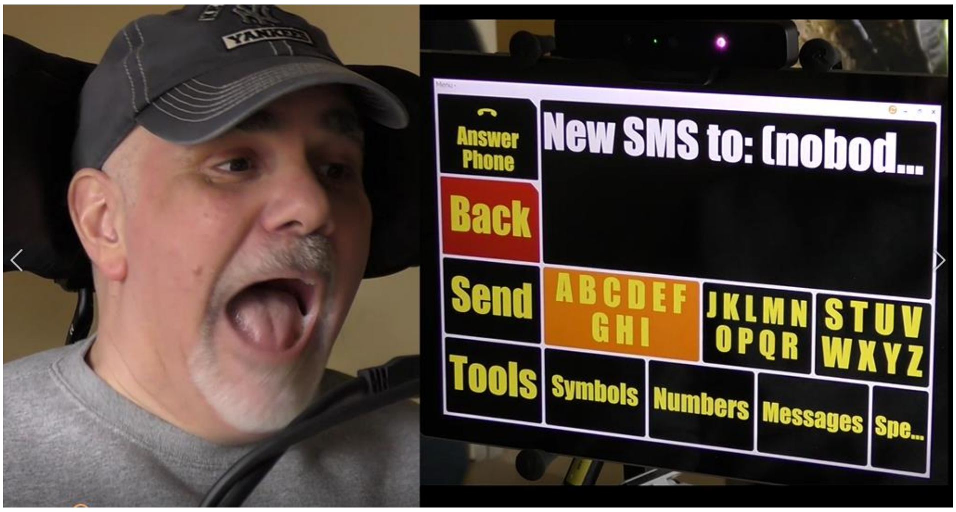

Figure 63: JA using FaceTracker system during trial - mouth open expression.

5.6.2. Questionnaire Feedback

Feedback on user comfort and system performance provided by JA in part one of the utility questionnaire is shown in Figure 64. This shows that overall JA found the experience a positive and successful one, areas he was less satisfied with were the accuracy and jaw fatigue experienced during the trial.

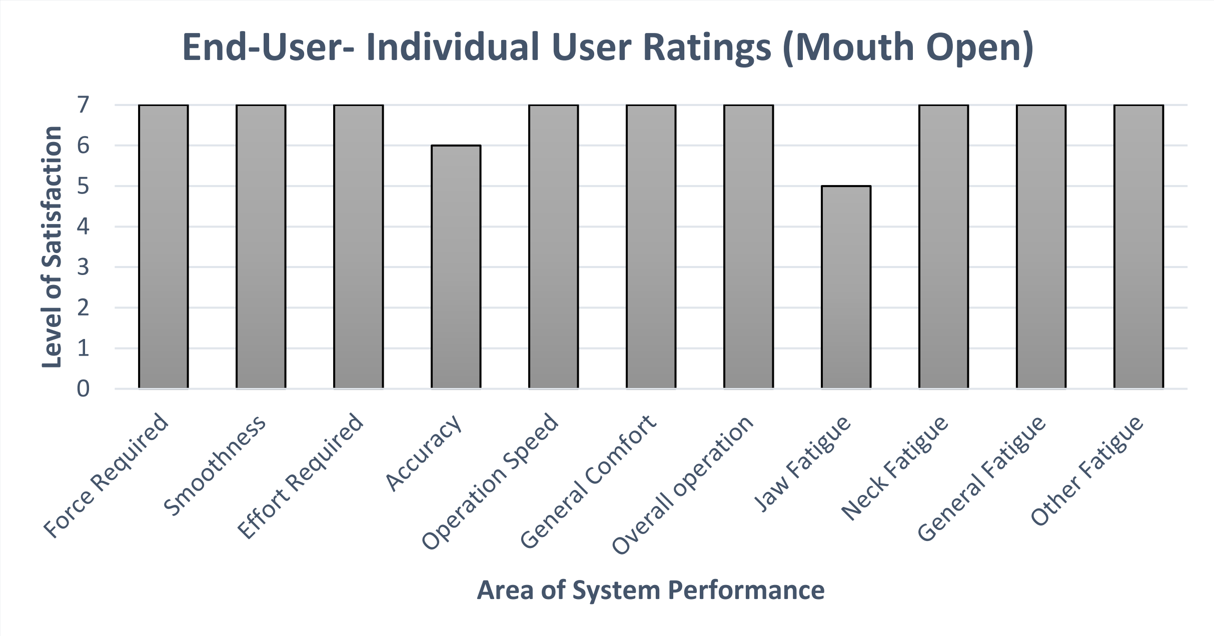

Figure 64: Utility Questionnaire Part 1 individual results for client JA.

In addition to this, JA also provided qualitative feedback in part two of the utility questionnaire, his comments for each question are listed below:

Question 1: What do you like or don't you like about the FaceTracker computer access method?

- *I like everything, I think it's marvellous!*
- *Frees up people to do things.*
- *If you can't move hands it gives people another avenue to do things.*

Question 2: Do you have any other suggestions for improvement to the system?

- *Other options for expressions*

Question 3: Do you think it would be useable in the environments that you would need to operate it in? Why?

- *Yes, mostly at home.*

5.6.3. Summary

Overall, JA had a very successful trial of the FaceTracker system and he was very excited about the possibility of a new access method technology. JA's home environment was observed to be a very good environment for FaceTracker to operate in as it was the most consistent in intentional activation rate out of all the trials – minimal system errors were observed. The system was set up in his lounge room with a good amount of natural light and no reflective surfaces. The area of performance highlighted by NSASA that JA could improve on with the FaceTracker system is that of applied force. This could simply be reduced by additional use and practice with the system and training with his occupational therapist to teach him that the level of mouth open expression does not need to be too large. This should in turn also minimise the level of fatigue experienced when using the system. During his trial JA also attempted the two-switch method of using FaceTracker – using 'mouth open' to advance and 'tongue out' to select. The only issue that JA had with this method is that when he used a 'tongue out' expression he opened his mouth to do so. This resulted in the first switch being activated accidently when he was intending to activate switch two to select. Fortunately, this problem was highlighted as an improvement that needed to be made to the detection abilities of FaceTracker and was integrated into a later version of the application. In addition to this, for Grid 3 access it was observed that JA also uses auditory feedback due to his eyesight limitations. This is another area of improvement to the FaceTracker system that could be implemented in the future – to enable independence of use for a wider range of people.

5.7. Client Case #4 – CH

CH is a client who has an autoimmune condition with quadriplegia post stroke and is primarily bedbound - as she is limited in her movement abilities she uses her neck/head as an access method. Currently she is using two switches: (1) a candy corn proximity switch placed to the left of her head (shown in Figure 65) to access her computer and (2) a spec switch placed to the right of her head to control her environment (turn TV on etc.).

Figure 65: Client CH using her current single switch method for computer access (candy corn switch).

The client has in the past utilised the candy corn switch under her chin for computer access and had a third switch to the left of her head for emergency calls, however she began experiencing high levels of exhaustion when performing the required action for this access method and therefore use has been discontinued. CH was identified as a potential end-user for FaceTracker due to need for a less fatiguing access method and so that she could potentially enable a third access point to have the ability to make emergency calls again.

As CH is bedbound, she currently uses a Microsoft Surface Pro 4 with Grid 3 switch scanning software mounted above her bed for computer access. Unfortunately, during the trial the FaceTracker system had difficulties consistently picking up CH's face and therefore detection of the mouth open expressions was also inconsistent. As shown in Figure 66 the 'Face out of frame' error was occurring regularly even though CH's face was completely in view and as a result she was not successful in carrying out any tasks for assessment. Once again, a different mounting system for the camera/tablet could be beneficial in helping to set up the correct positioning for proper face detection for client CH.

Figure 66: FaceTracker system mounted above bed during trial - showing 'face out of frame' error.

Notes taken during this trial and review of the video footage did however give good feedback for system analysis. Upon further investigation it was identified that the white pillow and blanket on CH's bed and/or the colour of the switches next to her head may have been interfering with the camera's ability to properly detect the face. A second trial was organised to test the system with a different coloured pillow case, however due to client illness was unable to be completed within the time frame for this part of the project.

5.8. Post-Testing Improvements - Integration with Grid 3

5.8.1. Access through Grid 3 for Users

A customised Grid 3 set was added to a general computer access template for access to the FaceTracker device as shown in Figure 63.

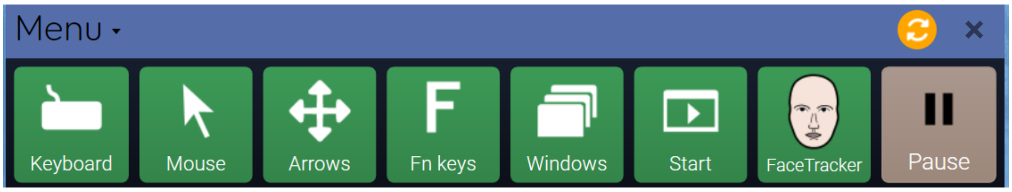

Figure 67: Customised Grid 3 computer access grid for access to FaceTracker grid.

This gave access to the customised FaceTracker grid page shown in Figure 64. The only way that Grid 3 could interact with FaceTracker was through shortcut keys – therefore short cuts were bound to certain commands in the FaceTracker application code. These shortcuts were then added as functions to the cells of the FaceTracker grid page.

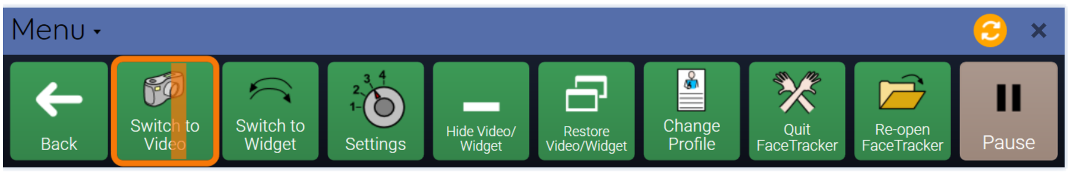

Figure 68: Customised Grid 3 FaceTracker grid for access to FaceTracker application.

This provides the user the ability to switch between the video and non-video feedback widget tabs (discussed in section 5.8.2), open the settings window, open the change profile window and quit the application completely. Additionally, options for hiding the widget and restoring it were added and an option to reopen the program if it was shutdown.

5.8.2. Docking

Docking of the FaceTracker application for use with Grid 3 was another piece of feedback with large importance given from the field experts. The video window was subsequently redesigned to be smaller so that it could be placed next to the Grid 3 keyboard without any interference. Being in the bottom right hand corner it is easier to see when switching is occurring when using the scanning software. The new design also incorporated a feedback page with (Figure 69) and without video (Figure 70) so that users can choose what type of feedback they want, or this window can also be hidden.

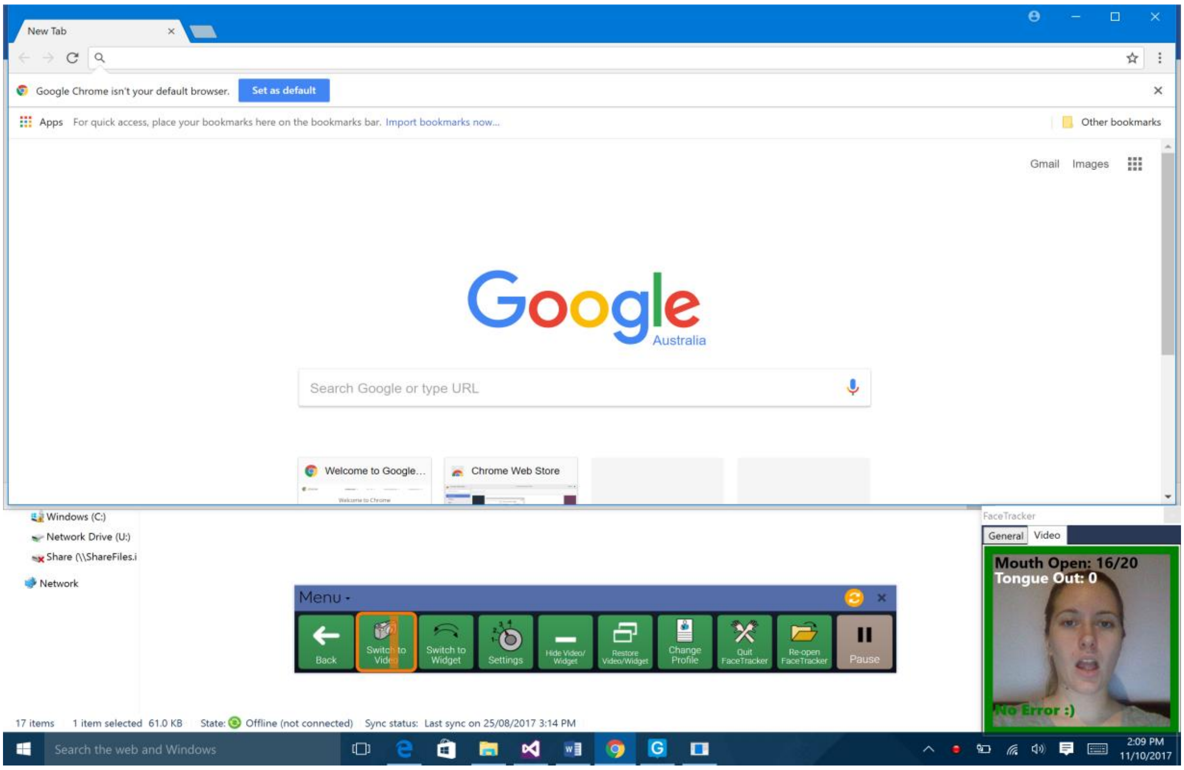

Figure 69: Newly designed FaceTracker feedback widget - showing video display.

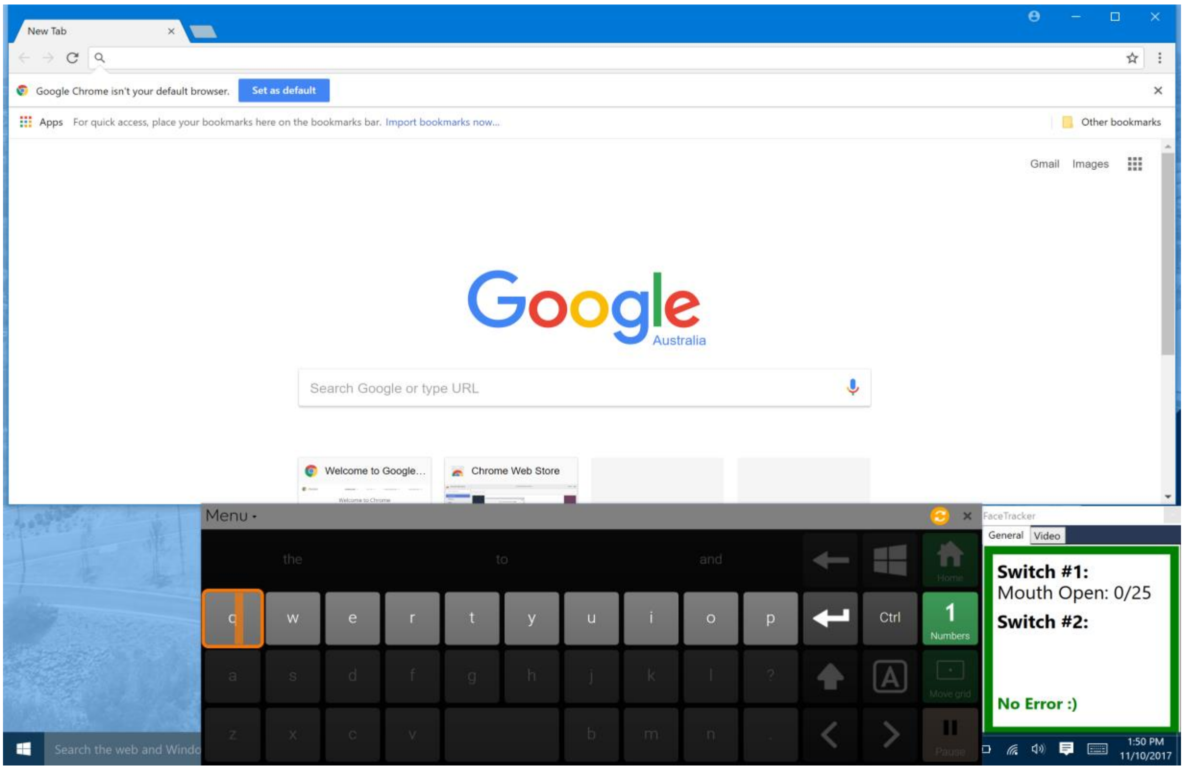

Figure 70: Newly designed FaceTracker feedback widget - showing non-video display.

The main application windows were changed in size so that it allowed for the Grid 3 keyboard and other computer access pages (mouse movement etc.) could be used to access the application without needing to move its location. This can be seen in Figure 71, Figure 72, Figure 73 and Figure 74. Figure 74 also highlights better that the user is able to test new settings whilst still using their current settings to interact with the application until the update button is pressed; a feature discussed in section 3.2.2.

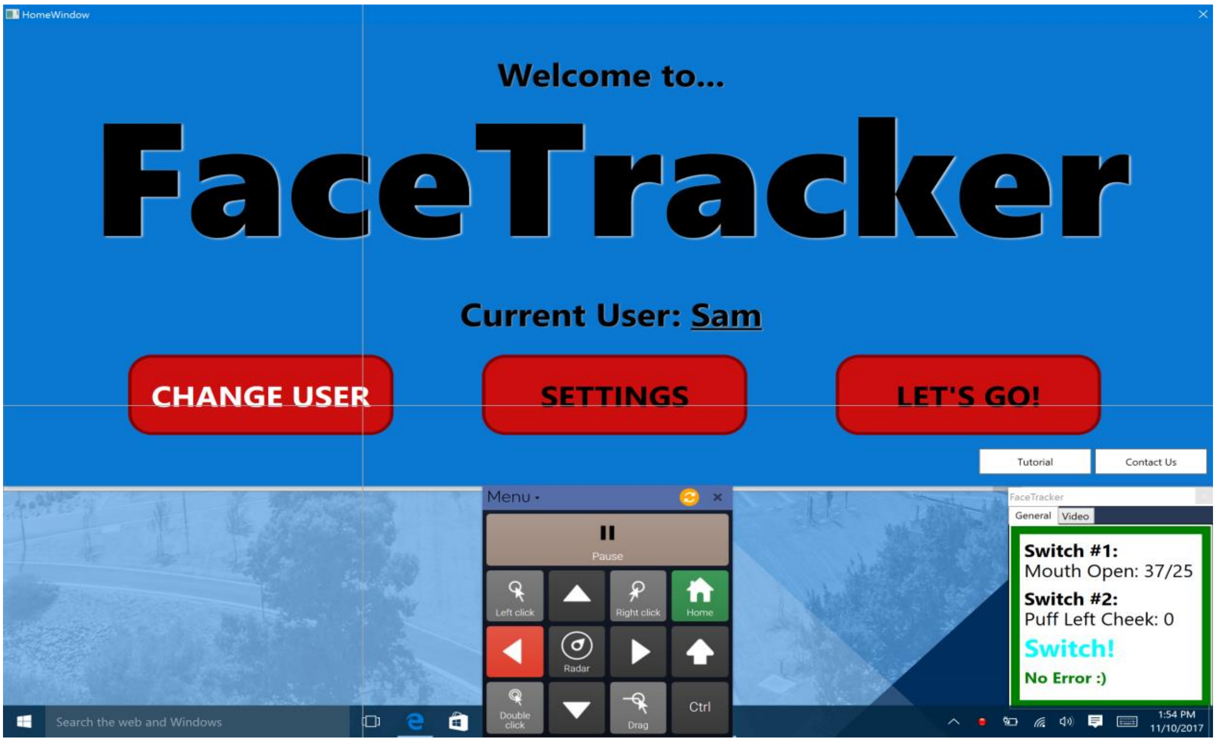

Figure 71: Adjusted application design - home window.

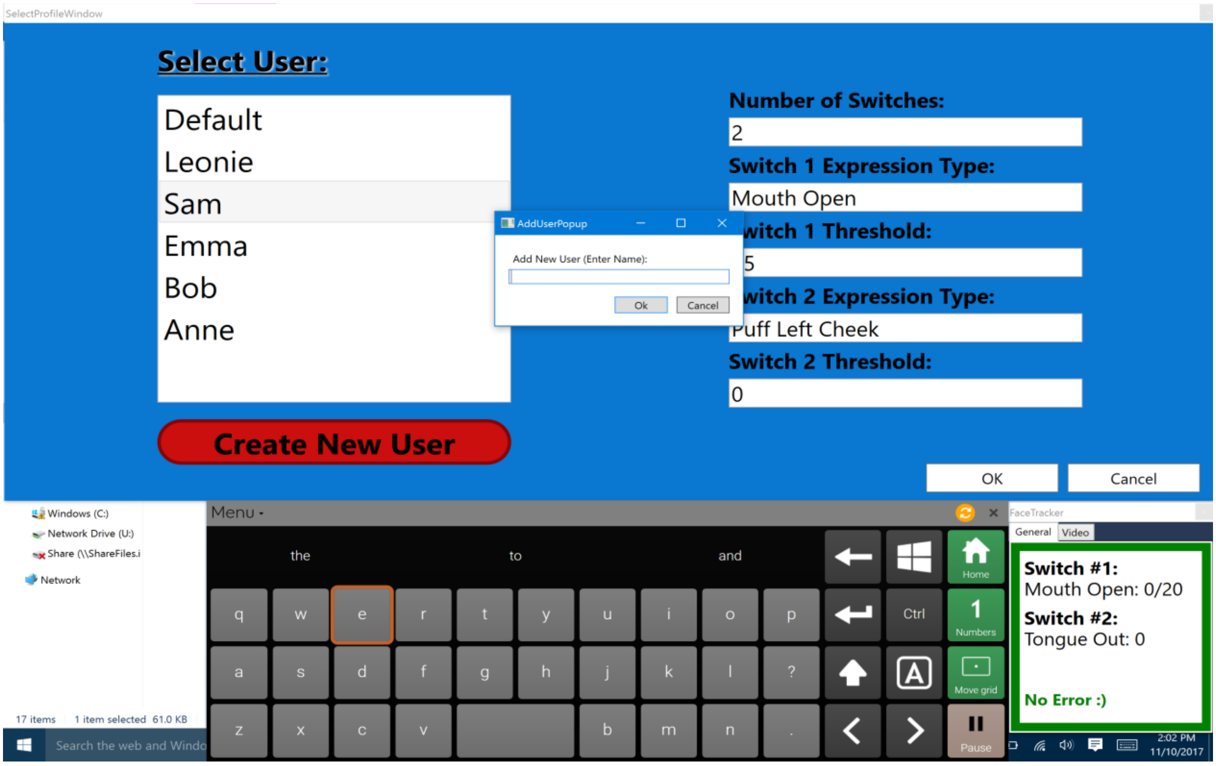

Figure 72: Adjusted application design - new user window.

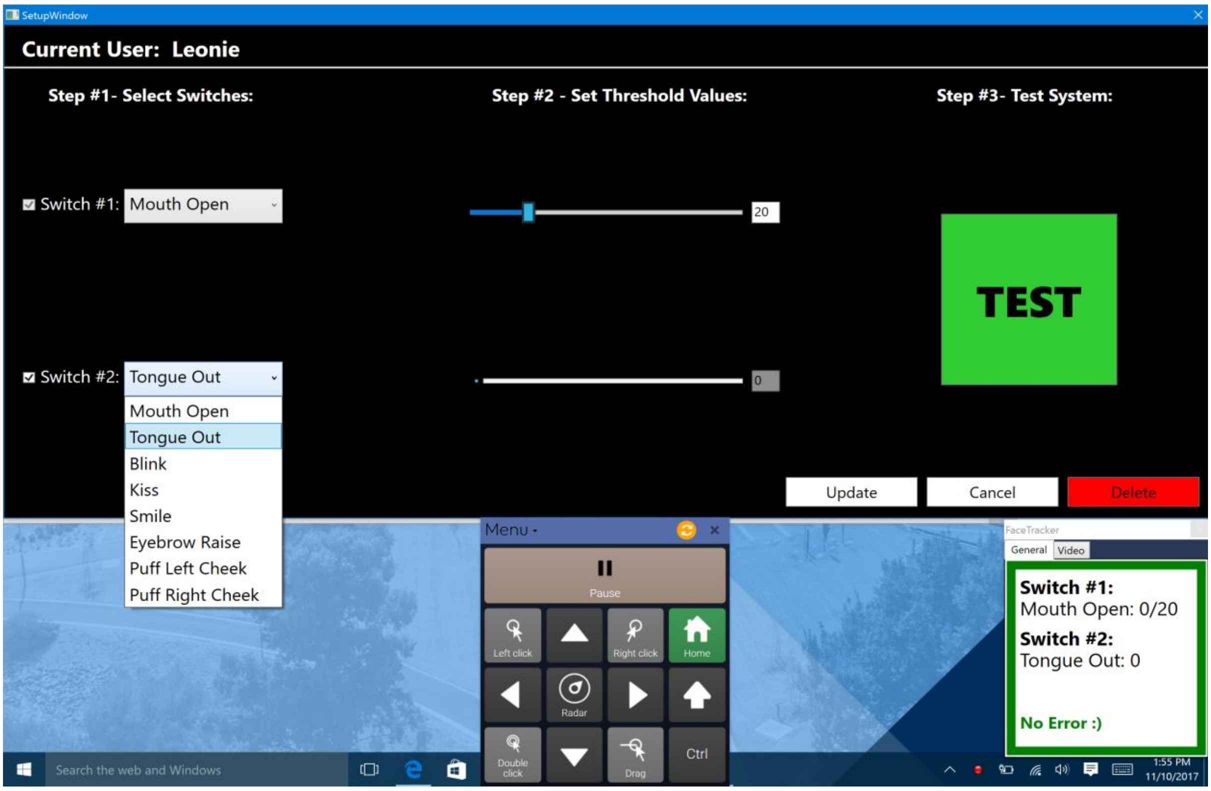

Figure 73: Adjusted application design - settings window.

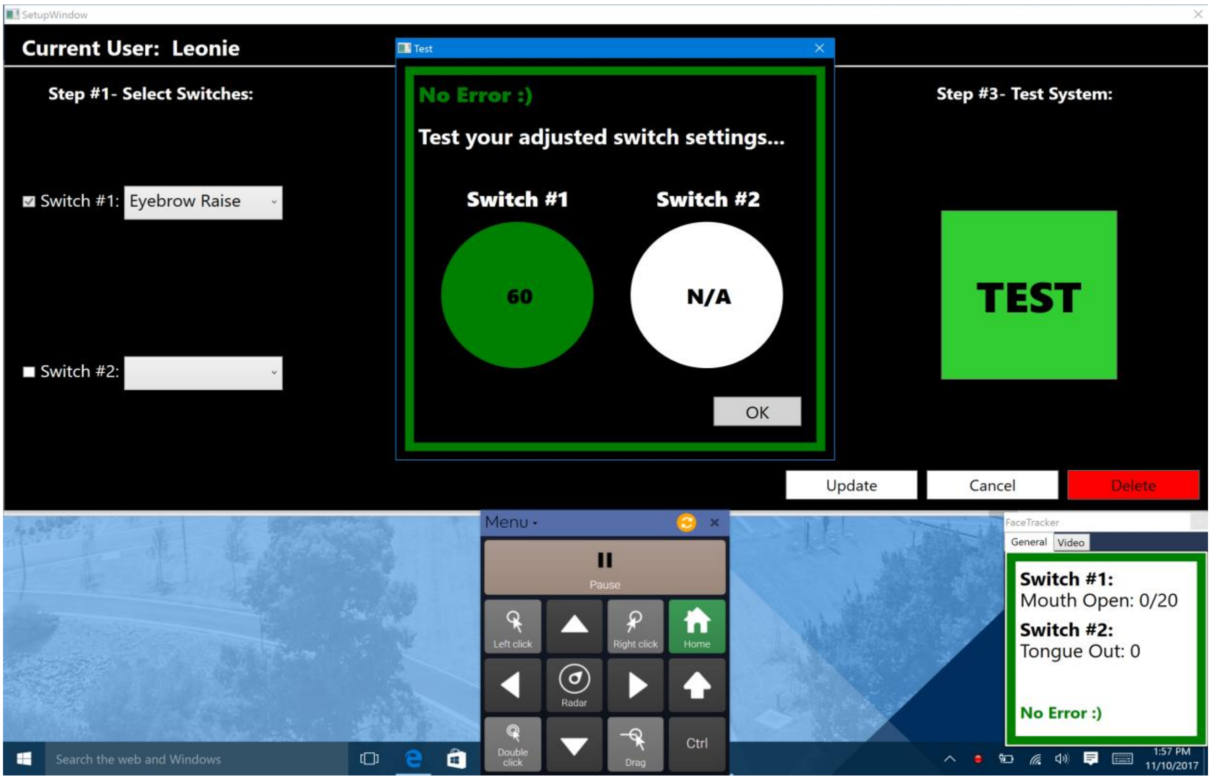

Figure 74: Adjusted application design - settings test window.

5.9. Post-Testing Improvements - Application Design

5.9.1. Face Lost Error

The 'Face lost' error occurred many times during trialling when light or glare was interfering with the cameras detection ability. An orange border was integrated into the system (as shown in Figure 75) to show this error as sometimes detection of an expression was still possible during this time – it was just not as consistent. Therefore, it was important that switching activity still be picked up by the Grid 3 software instead of being disabled like the other two errors are when they are detected. For differentiation from these two errors which do not enable switch activation to prevent accidental switch activations – the orange border is used in comparison to the red border the other errors display as shown in Figure 76 and Figure 77.

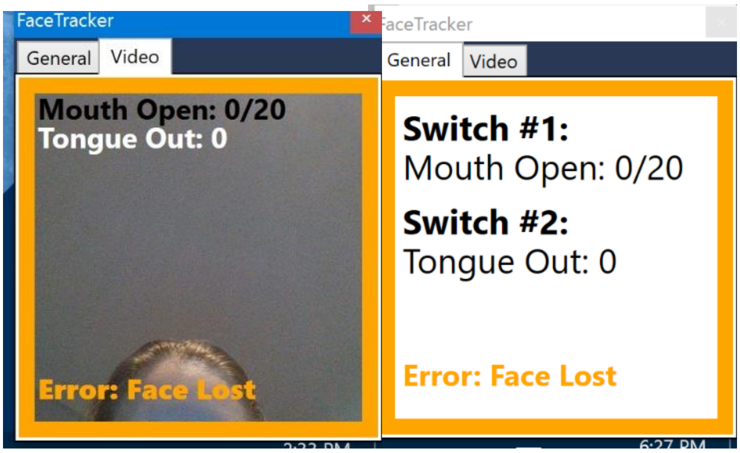

Figure 75: Feedback display widget showing orange border for 'face lost' error.

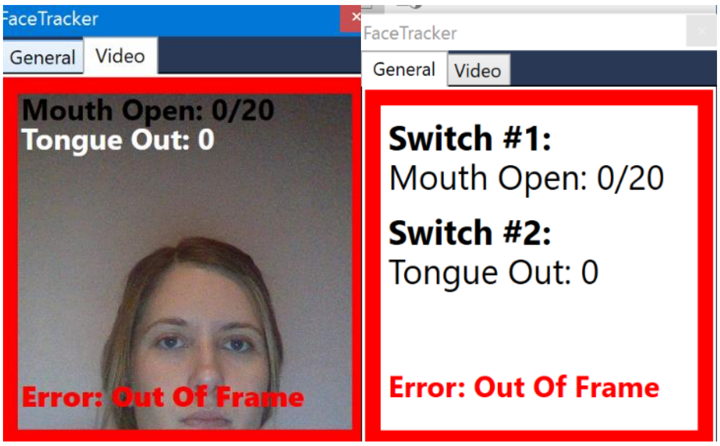

Figure 76: Feedback display widget showing red border for 'face out of frame' error.

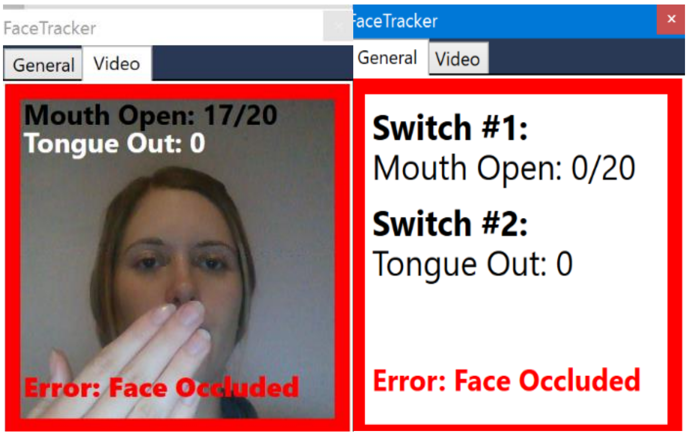

Figure 77: Feedback display widget showing red border for 'face occluded' error.

5.9.2. Pausing of System

Another point of feedback from the field experts surrounded the ability for the user to see when the system was paused more clearly and to be able to pause the camera for battery saving purposes instead of just the Grid 3 switch scanning. Unfortunately, if the user were to pause the camera through a Grid 3 cell function they would not be able to unpause it as the camera would no longer be detecting them – they would need assistance or another method of access (e.g. mechanical switch) to restart the system. Therefore, this ability was kept in the context menu so that therapists or caregivers have the ability to pause the system completely and the video/widget shows that the system is paused as shown in Figure 78.

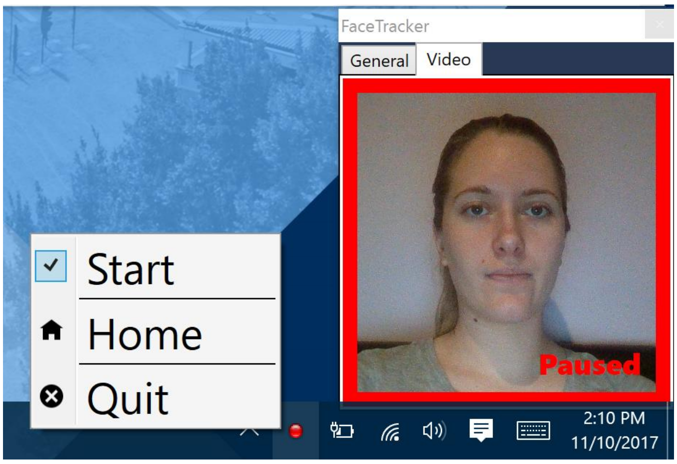

Figure 78: Feedback display widget showing paused camera via taskbar icon menu.

However, Grid 3 was set up to include a pause button on every page which when selected stops switch access and turns red to visually show that it is paused as shown in Figure 79. This option allows FaceTracker to continue running so that the user can unpause by selecting the pause button again. In addition to this, users can also have the long hold option set up for pausing Grid 3 wherever they are in the application. This option requires users to hold the selected expression for a selected amount of time (e.g. 2-3 seconds). The downside to this method however is that it is not very visual that the system is paused which is why improvement was suggested initially during the trial.

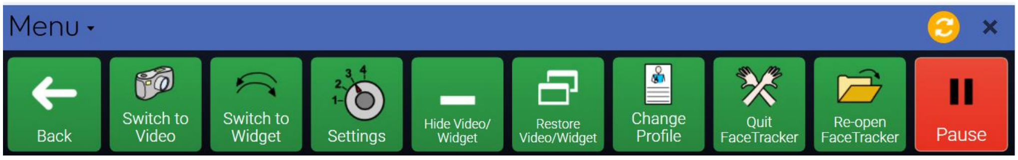

Figure 79: Grid 3 FaceTracker set showing paused system via red highlighted cell.

5.9.3. Addition of Blink Expression

As per feedback from client RE, a blink expression has been added as a switching option – this expression is more natural and therefore hopefully will be less fatiguing than some of the other expressions. Again, this will be dependent on personal preference. As this is a very recent update - currently the 'blink' expression will detect any complete closing of two eyelids, so natural blink is likely to set off some unintentional switches. To resolve this the Grid 3 software will need to be set up so that it only detects a long hold of the expression and not quick fluttering of the eyelids. In future work this will need to be built into the expression selection to be a 'long blink' and not an adjustment that needs to be made in Grid 3.

5.10. Post-Testing Analysis - Effect of Various Lighting Conditions on Tracking

Following the trials, a brief investigation into the effect of glare, bright light and backgrounds was undertaken. The conditions analysed included: normal room lighting, low lighting indoors, bright light indoors with a reflective surface in the background, sunlight from window whilst indoors, sunlight whilst outdoors and detection with a white pillow versus different coloured pillow for use of the system in bed.

5.10.1. Normal Light

The tracking ability of FaceTracker is very accurate in a room with a good amount of light that is non-directional. The system was tested at various angles for detection and was consistent in detection as displayed in Figure 80

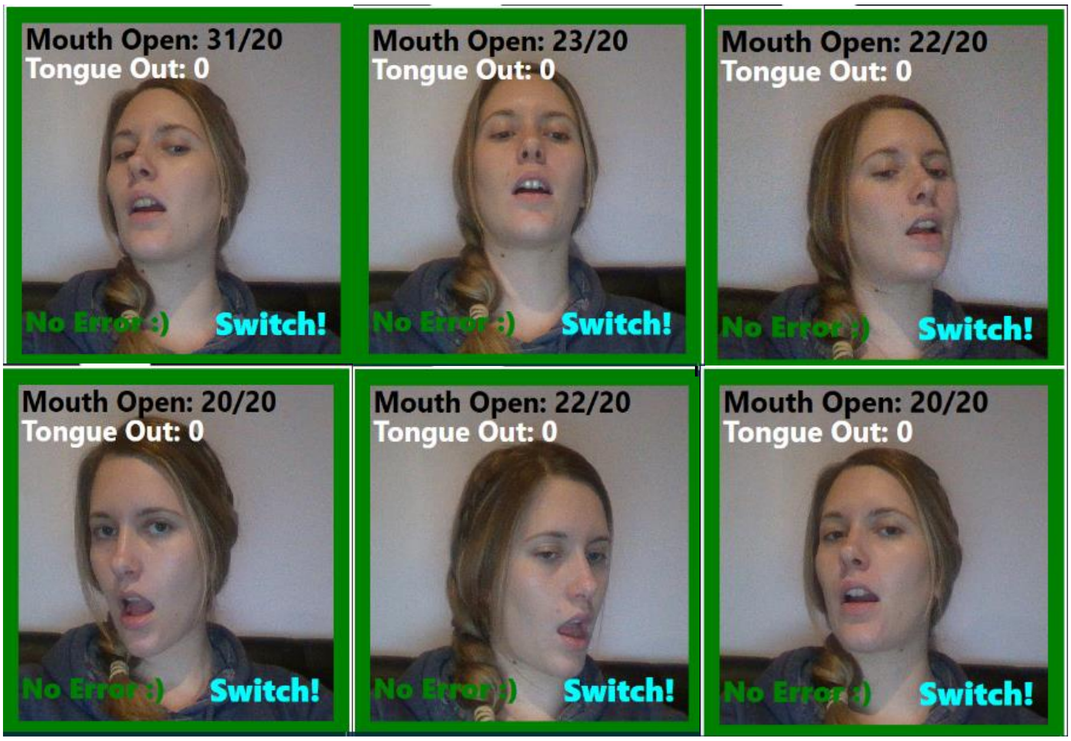

Figure 80: Testing of FaceTracker in normal indoor lighting conditions.

5.10.2. Low Light

The detection ability of FaceTracker in low light is shown in Figure 81, it was observed that there was consistent detection in low light – however if the computing device used had maximum brightness the detection was sometimes a little bit inconsistent as shown in the bottom row of photos.

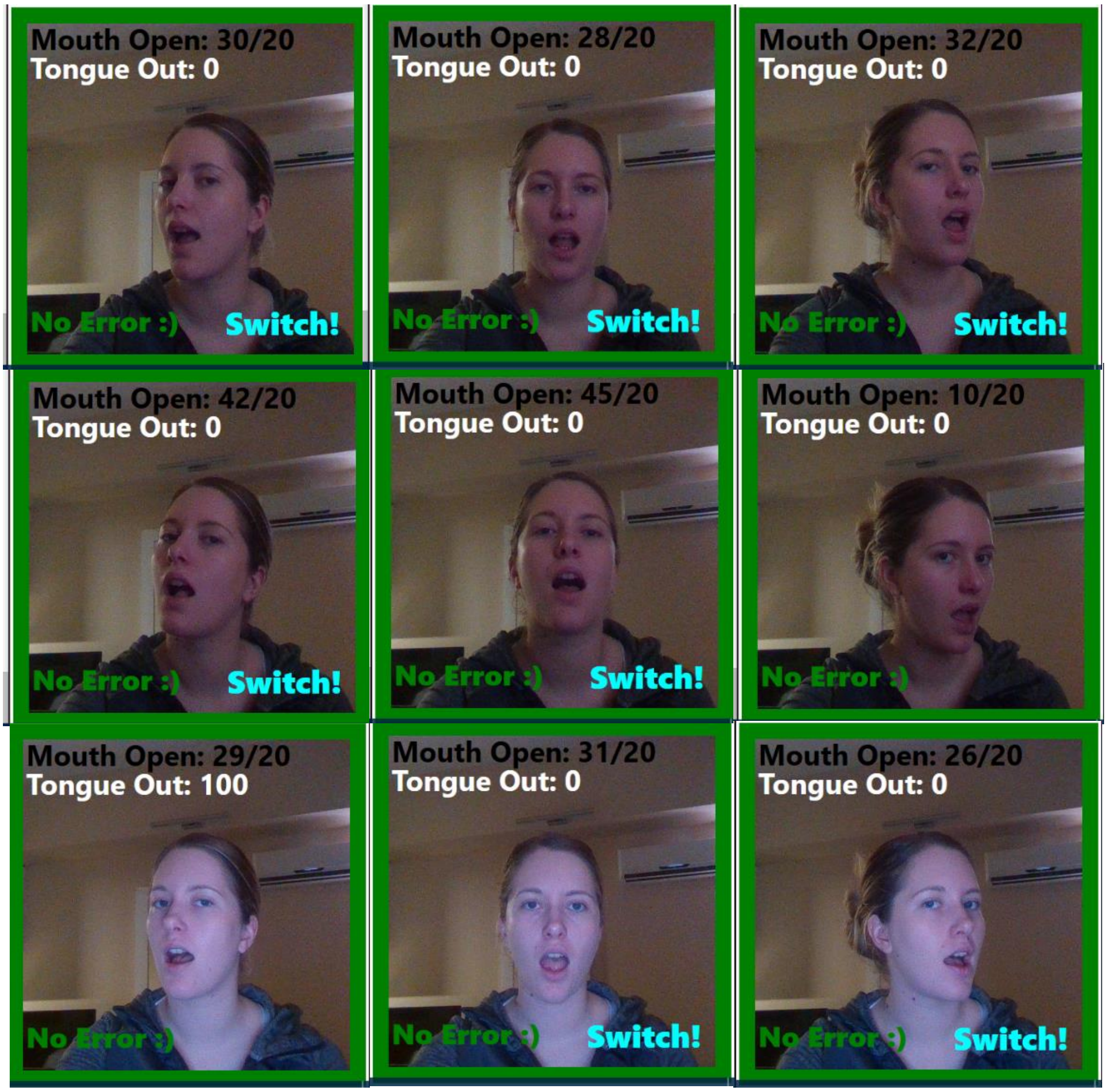

Figure 81: Testing of FaceTracker in low indoor lighting conditions.

5.10.3. Bright Light/ Reflective Surface

During trials bright directional light in combination with a reflective surface in the background of face tracking area caused issues in consistent expression detection and often caused the ‘face lost’ error to show. This was confirmed during this analysis with Figure 82 showing a variety of detection levels. This includes the detection of a ‘mouth open’ expression when the user is not performing this expression (bottom right photo), no detection of the expression when the user is performing the action (bottom middle photo) and the detection of the expression although the application is showing an error of ‘face lost’. Confirming the need for the application to still allow for switching to occur when this error is shown, hence the addition of the orange coloured border as discussed in section 5.9.1.

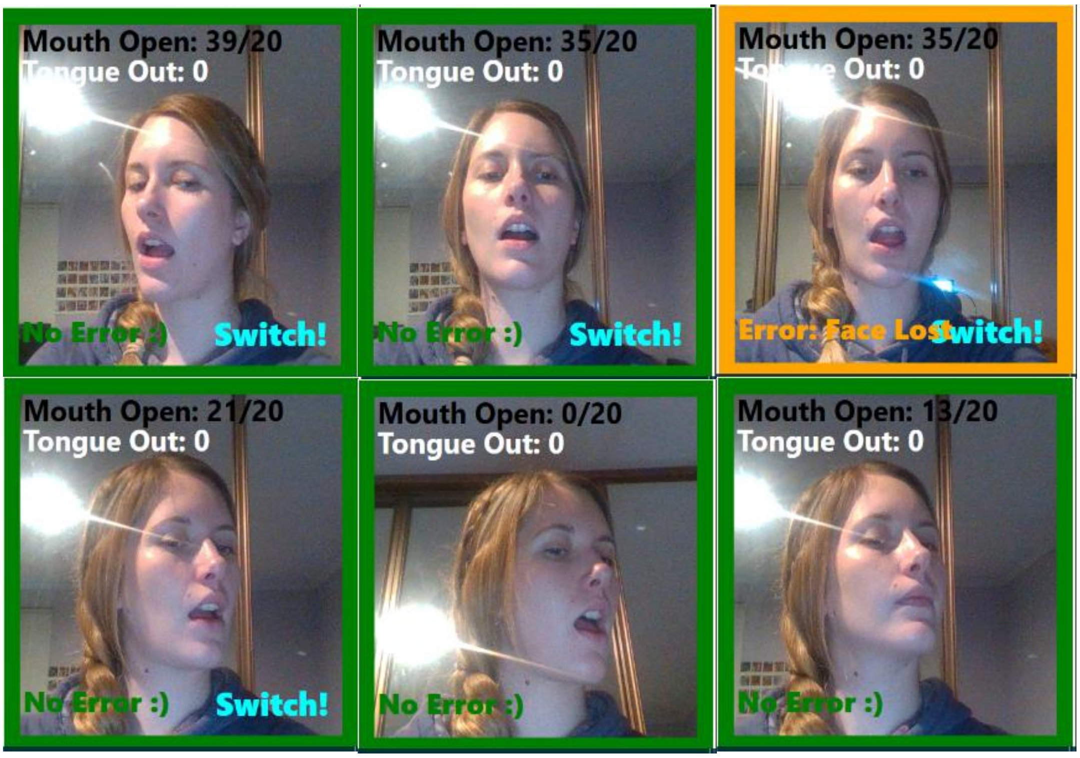

Figure 82: Testing of FaceTracker in bright lighting conditions with reflective surface.

5.10.4. Sunlight from Window

Using the FaceTracker system close to a window light source had a variety of impacts on tracking ability. Depending on the particular shadow cast on the users face from the light resulted in the camera being either consistent or inconsistent at different angles. An example of window light directly in front of the user is shown in Figure 83, window light from the left of the user is shown in Figure 84 and from the right side in Figure 85.

Figure 83: Testing of FaceTracker in sunlight from window lighting conditions- direct light.

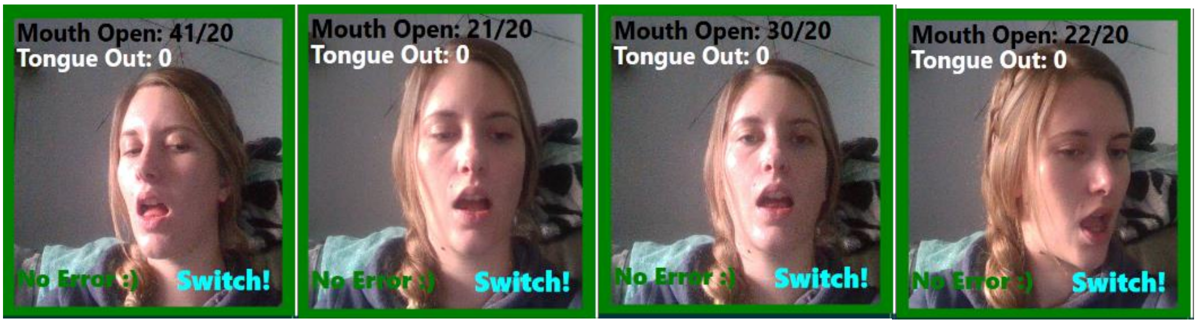

Figure 84: Testing of FaceTracker in sunlight from window lighting conditions - from left side.

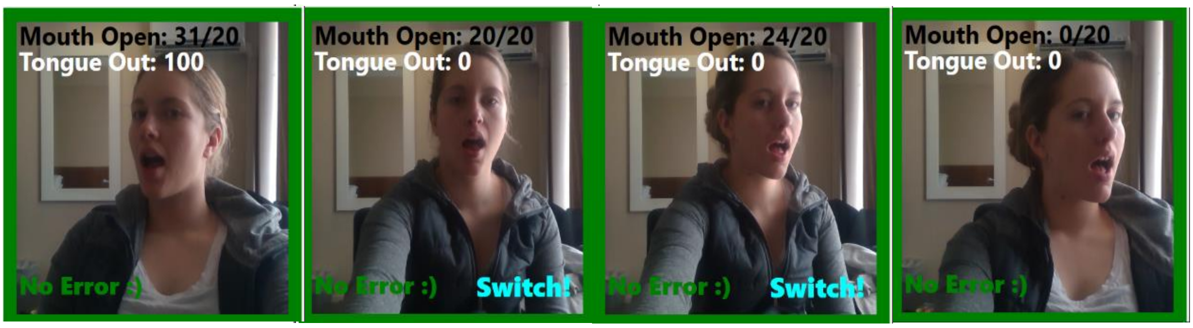

Figure 85: Testing of FaceTracker in sunlight from window lighting conditions – from right side.

5.10.5. Sunlight Outdoors

Trialling of the FaceTracker system in the outdoor environment did not provide good tracking capabilities – the system occasionally detected an expression when sunlight was in front of the user (as shown in the third picture of first row and first picture of second row in Figure 68), however was not at all reliable. This is likely due to the presence of external infrared frequencies of light from the sun interfering with the infrared cameras abilities.

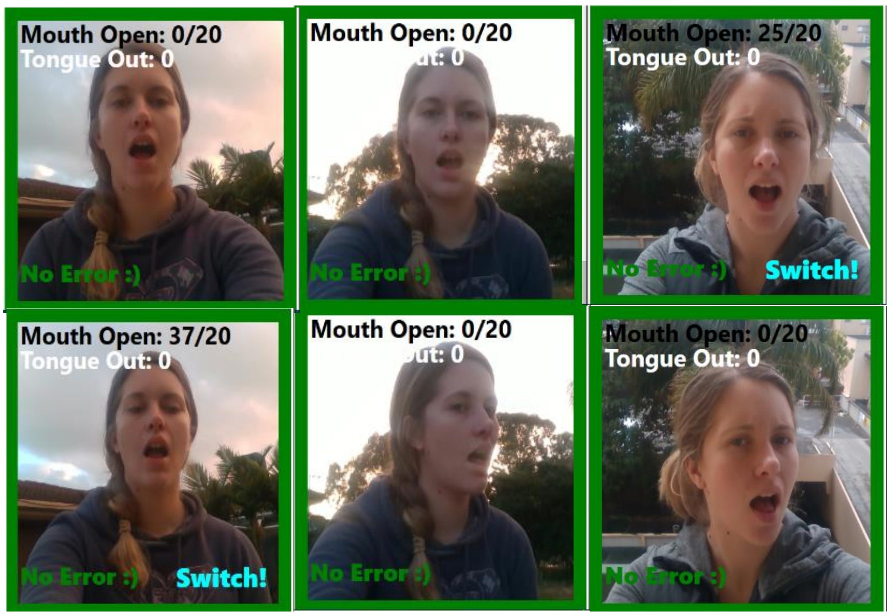

Figure 86: Testing of FaceTracker in outdoor lighting conditions.

5.10.6. Lying in Bed

Testing of the cameras tracking ability in a bed situation was brought about due to the inconsistencies in tracking experienced with client CH as discussed in section 5.7. It was hypothesised that the white pillow / blanket was causing issues with the cameras tracking abilities. A similar result was found when the situation was recreated as shown in Figure 87, with the 'face out of frame' error often occurring similar to client CH's trial.

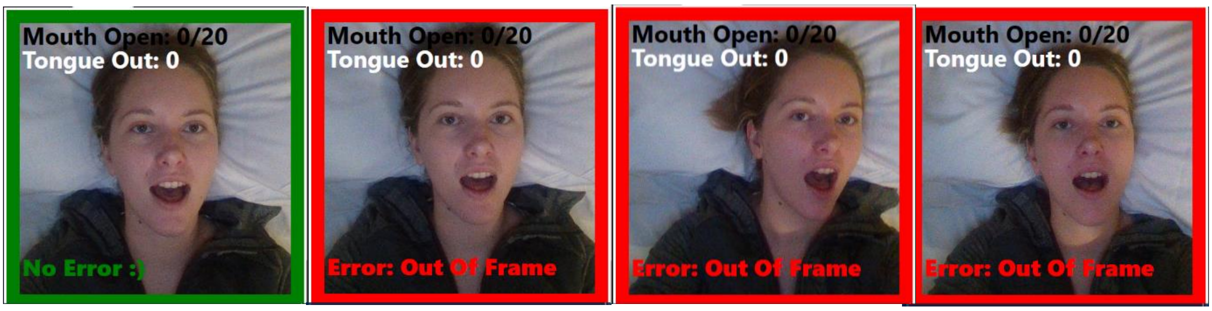

Figure 87: Testing of FaceTracker in bed (white pillow) – low lighting conditions.

A grey and black pillow were also trialled which resulted in a much better but still not 100% consistent detection ability of the camera, however no 'face out of frame' error occurred as shown in Figure 88 and Figure 89. The grey pillow was trialled in similar low lighting conditions to the white pillow, however the black pillow was used with light from the window brightening the face.

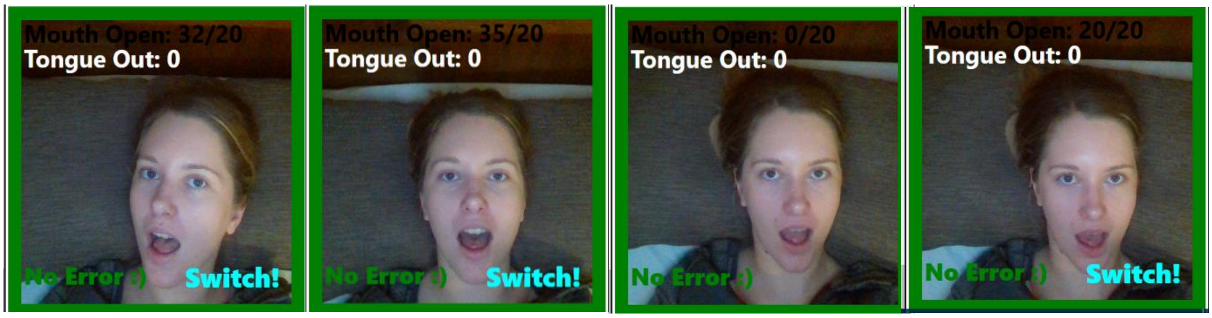

Figure 88: Testing of FaceTracker in bed (grey pillow) - low lighting conditions.

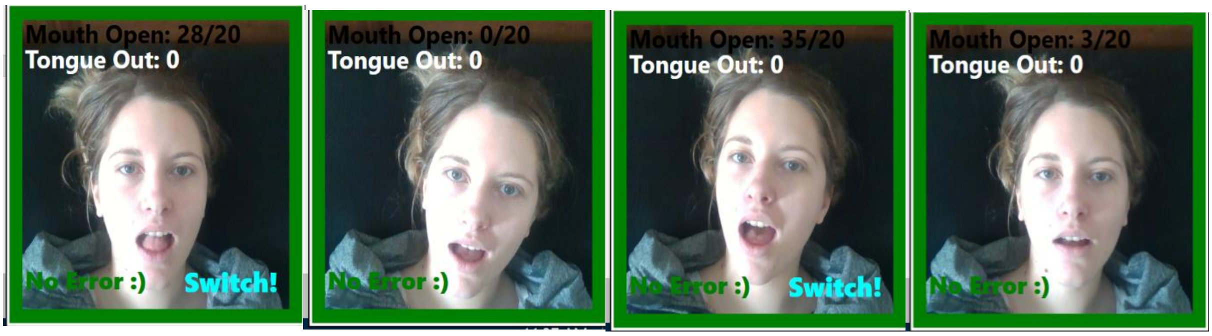

Figure 89: Testing of FaceTracker in bed (black pillow) – sunlight from window lighting conditions.

Finally, the white pillow and blanket were once again trialled with light from the window brightening the environment as shown in Figure 90. This trial resulted in better tracking than in the low lighting seen in Figure 87, even with the addition of a blanket also around the face and wearing glasses. Sometimes the 'face out of frame' error still occurred as seen in the second and third photos of row one, however detection of the 'mouth open' expression was still occurring successfully. This highlights that a variety of factors predominantly surrounding lighting may have been impacting client CH's trial and not so much the colour of her bedding. Some potential influential factors could be the shadowing from the laptop above her and the fact that her other two switches were also beside her head. These factors may need to be adjusted until the system successfully is able to detect her movement consistently.

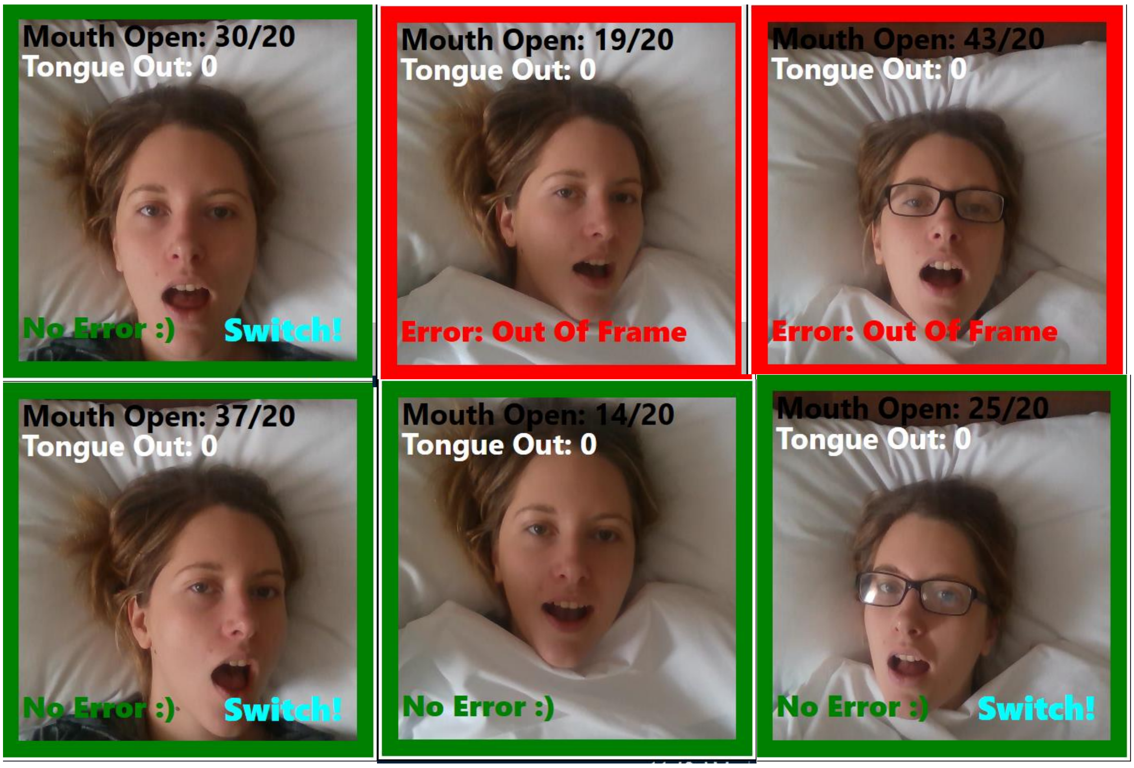

Figure 90: Testing of FaceTracker in bed (white pillow) – sunlight from window lighting conditions.

5.11. Post-Testing Analysis - System Use with Other Computer Access Methods

Feedback from the pilot trial highlighted both the challenge it was for some users to use two different expressions for two-switch scanning with FaceTracker, as well as the potential benefit for the system to be used in conjunction with other devices already on the market. The Surface Pro 4 could not be used with the Surface Pro 3 Docking Station, so for testing purposes the less powerful Surface Pro 3 was used to ensure that the Surface Dock would be a successful way of enabling alternate switches and/or environmental control to be used with FaceTracker. FaceTracker was first tested with a mechanical button switch connected to the Surface Docking Station USB port via a JoyCable2 switch connector as shown in Figure 91, Grid 3 was set up to switch one was controlled by FaceTrackers 'mouth open' expression and switch 2 was controlled by the mechanical button press.

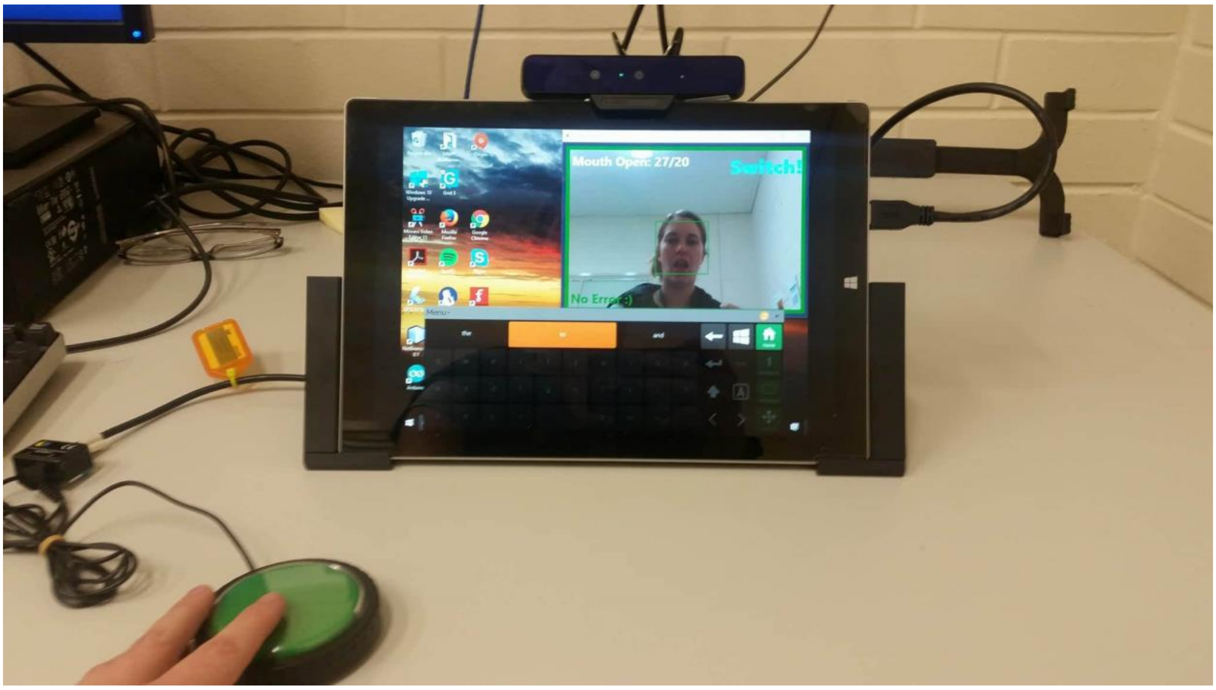

Figure 91: Testing of FaceTracker with mechanical switch.

'QUHA Zono' was similarly set up so that the device controlled the mouse cursor movement and facial expression was used as a mouse button click as shown in Figure 92. The combination of these two systems becomes similar in function to the 'Smyle Mouse' but with a larger choice of expressions.

Figure 92: Testing of FaceTracker with QUHA Zono mouse pointer device.

6. Conclusions

The aim of this project was to create a potential alternative switch access solution that could be used by people with severe or multiple disabilities who have limitations in their abilities to use other access technologies for communication, computer access and/or environmental control. In particular, it was designed to meet the needs of client EK- the motivation behind the project, who has large amounts of dystonic movement of his head and neck and therefore has been unsuccessful in finding an effective access method.

The objectives of the project were fulfilled and a user-friendly application was successfully developed. Trials of the system showed that there had been areas of improvement upon previous work including improved tracking of dystonic head/neck movements of EK without lagging or freezing of the application. Users were also successfully able to talk, laugh and smile while using the application with the 'mouth open' expression and only experienced minimal accidental activations, caused by expressions made by yawning or coughing. The developed application also not only allowed for therapists or caregivers to easily change detection settings of the device but also allows for users to independently do so which is a large benefit over the 'proof of concept' prototype. Finally, a larger range of expressions for use as a switch input were successfully integrated into the system to cater to a wider range of capabilities and personal preferences of users.

Observations and feedback from testing of the system also highlighted areas of potential improvement. Some of these improvements were subsequently integrated into the system including the design of a specific Grid 3 set and adjustment of the FaceTracker layout to allow for easier access to the application for users. Another improvement made to the system was the integration of a blink expression and better visual feedback to users that the system is paused. Finally, the system was also successfully tested for its integration capabilities with other commercially available devices including a mechanical switch and the QUHA Zono head pointer. This confirmed that FaceTracker could not only be used individually as a single or double switch step scanning solution itself, but could also potentially be used in conjunction with another switch input device or to provide the 'mouse click' action for direct input systems such as head pointers and Eyegaze systems.

However, there was a limitation to the device discovered during trials involving the environmental lighting that the user is operating the FaceTracker system in. These confirm the manufacture recommendations for use – indoor only. Strong directional lighting such as that provided by downlights and sunlight caused inconsistency issues due to shadows and glare affecting the Intel RealSense Camera's detection ability – this is an area which will need to be investigated further.

6.1. Significance of Research

Although environmental lighting and glare is a limitation of the FaceTracker system, other access methods such as eye-gaze systems also suffer from this limitation and remain suitable and beneficial for some clients depending on the environment they require use in. While the system is targeted for end-users who do not have a reliable access method, this device could also be used as an alternative to other access methods or may provide a second switch input method for those who did not have this option previously. Consequently, the results of this project provide a significant contribution to research in the access technology field and expands the knowledge and understanding of the use of 3D camera detection of facial expressions for switch access.

6.2. Limitations of Research

A major limitation of the testing method included firstly that due to time limitations of the project, only a small number of end-user participants could be recruited and therefore no statistical analysis could be performed. Ideally users would have also had an extended period of time to practice using the FaceTracker system before the trial was undertaken so that an accurate comparison could be made between their current access method and the FaceTracker system. This is something that could be rectified in future trials.

A second limitation of the research was that due to the testing being undertaken with people with a disability, activities completed for testing sometimes drifted from their intended outcome. This is something that is difficult to prevent, but unfortunately meant that the aim of having a single task that was consistent for comparison between not only the varying clients but also between the client's current method of access and that of the FaceTracker system was not completed. Senior OT Annabelle did however get these clients to complete a similarly challenging task so that there would still be a good level of comparison for NSASA scoring.

The final limitation of the testing method was that although the adult clients had intended to have their feedback recorded by a caregiver, at the time of testing caregivers were not present so feedback had to be provided verbally and recorded by the development team. This may have potentially affected the response given by participants, however due to lack of staff resources and wanting to keep numbers to a minimum for home visits a non-involved person for recording client feedback could not be provided.

6.3. Future Work

To conclude the work of this thesis, this section will provide recommendations for areas of the project that could be further analysed, investigated and improved upon in the next stages of development of the FaceTracker system.

6.3.1. Further Research into the Effect of Bright Light and Glare on System

As the effect of bright light and glare is the largest limitation of the system currently it is important for further analysis and research into this area to be undertaken. Some potential steps forward may include:

1. Trial of two updated Intel cameras from the SR300 – D415 and D435 (recently announced), these cameras have specifications showing indoor and outdoor use and 30FPS higher depth sensing than the SR300 (Intel, 2017b). Therefore, it would be useful to test if the new camera has a reduced interference from bright light and glare on detection of facial expressions.

2. Using the detection of particular facial landmarks individually and creating a new algorithm for detection of their movement rather than relying on the algorithms from the SDK for particular facial expression detection – as it is not clear exactly how this works. This could be a way to potentially minimise the effect of glare by only needing particular sections of face to be correctly detected.

3. The integration of a calibration system could also potentially help with improved face tracking ability in sub-optimal lighting conditions. Although a current benefit of the FaceTracker system is that it does not need calibration, if it could help improve detection then this is something that should be considered. The Intel RealSense SR300 SDK has a feature of user recognition that creates a database of photos to help with recognition of various users. This database could potentially be used to help fill in the landmarks of the face that the camera is having difficulty detecting to help improved tracking capability.

4. Investigating the effect of changing the camera setting to high motion detection may have had on detecting consistency. This may not have made any significant changes but if there was an impact, a setting to enable/disable this setting for different users could be integrated into the system.

5. Research into whether the development of an encasing for the camera that blocks light from accessing the camera aside from directly in front it where the user is being detected could be beneficial to the system. A filter could also possibly be implemented to help with outdoor use. If this could reduce the level of environmental infrared light and glare being reflected into the camera this could also be a potential solution for improving the reliability of tracking.

6.3.2. Further Testing of the System

Further testing is required to determine if the FaceTracker system could be an effective and reliable commercial product. This testing should include not only a larger sample size but also be expanded in scope to not only investigate the effectiveness of the 'mouth open' expression but all of the other expressions as well. Trials could also be held for the use of FaceTracker as a second switch for those who currently can only use a single switch. The participants could also have more exposure and practice with the system before being assessed.

6.3.3. Application Adjustments

Based on feedback from the trials, additional adjustments to the application that could be made include:

1. Further expression detection refinement by not allowing switch activation outside of a certain angle range. The Intel RealSense SR300 allows for face position detection - degrees of roll, pitch and yaw. This information could be used to reduce the accidental activations mentioned by staff particularly for 'kiss' and 'eyebrow raise' expressions upon turning of the head. Although these two expressions were affected the most, from the investigation into the effect of lighting on the system detection turning the head to the side could also set off accidental activations for other expressions such as 'mouth open'.

2. The newly integrated blink expression needs to be adjusted to detect an intentional long blink so that the switch is not accidentally activated by natural blinking. Currently this can be set up through the Grid 3 software; however it would be advantageous for the FaceTracker system to already have this integrated.

3. Integration of pictures/descriptions of the specific expression movements that need to be undertaken (e.g. smile expression needs to be conducted with a closed mouth) into the application settings page. Additionally, a tutorial that users can look at before using the system and a user manual to help with set-up and troubleshooting should be created.

4. Creation of new version (or additional versions) of the application that can be used on multiple platforms, particularly iOS. The ability for the application to be used on various screen sizes is also important – this could be a feature that the application automatically adjusts or different versions of the application could be developed for commonly used screen sizes.

5. Addition of the ability for the application to change layout to suit different switch scanning software (e.g. Tobii Communicator). A customised switch scanning software display layout for FaceTracker will also need to be developed for alternate software – similar to the FaceTracker grid set created for Grid 3.

6. Implementation of audio feedback (aside from that already given in the testing section of the settings page) could be integrated into the application. This would be beneficial for those with visual difficulties so that they could be included in having the ability to independently change the settings of FaceTracker.

7. Expansion of the application to incorporate the eye-gaze tracking, voice activation and detection of hand gesture features of the Intel RealSense SDK to provide further additional or combined access options for users.

6.3.4. Investigate Mounting Options

Further research also needs to be undertaken into better mounting for the camera on 2-in-1 devices such as the Surface Pro 4 used in this project. The camera does not attach very well to the device and if the system were to be mounted on a wheelchair the stability would further decrease. Additionally, it would also be beneficial for the camera to be set upon a mount that could provide further degrees of rotation, such as via a ball joint attachment, so that the tablet did not need to be positioned directly in front of the user for consistent and reliable switch activations to be made. If this mounting system could also tidy up the loose wires of the system this would also be beneficial in providing a much neater and durable complete solution setup for clients.

7. Appendices

7.1. Appendix A – FaceTracker Code Sample

```
/*******************************************************************************

INTEL CORPORATION PROPRIETARY INFORMATION
This software is supplied under the terms of a license agreement or nondisclosure
agreement with Intel Corporation and may not be copied or disclosed except in
accordance with the terms of that agreement
Copyright(c) 2013-2014 Intel Corporation. All Rights Reserved.

*******************************************************************************/

using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows;
using System.Windows.Controls;
using System.Windows.Data;
using System.Windows.Documents;
using System.Windows.Input;
using System.Windows.Media;
using System.Windows.Media.Imaging;
using System.Windows.Navigation;
using System.Windows.Shapes;
using vJoyInterfaceWrap;
using System.Threading;
using System.Drawing;
using System.IO;
using System.Data.SQLite;
using Hardcodet.Wpf.TaskbarNotification; //open source library used to create taskbar icon https://www.nuget.org/packages/Hardcodet.NotifyIcon.Wpf/

namespace Face_Tracker
{
    /// <summary>
    /// Interaction logic for MainWindow.xaml
    /// </summary>
    public partial class MainWindow : Window
    {
        ...

        public MainWindow()

        {
            InitializeComponent();
            ...
            //Command bindings for shortcut key inputs to application
            ...
            // Create an instance of the joystick
            ...
            // Configure the face tracking mode module
            ConfigureRealSense();
            // Start the Update thread
            updateThread = new Thread(new ThreadStart(Update));
            updateThread.Start();
        }

        //connect to SQLite database
        ...

        private void ConfigureRealSense()
        {
            //Start SenseManager and session
            ...
            //Enable colour stream
            ...
            //Enable face module
            ...
            //Configure 3D tracking
            ...
            //Do not enable tracking of pose
            ...
            //Enable detection of face
            ...
            //Track faces based on closest face to camera
            ...
            //Only allow a maximum of 1 face to be detected
            ...
            //Enable detection of face landmarks
            ...
            // Enable detection of face expressions
            ...
            //Enable alerts
            ...
            //Mirror image
            ...
            //Release resources
            ...
        }
```

```
private void Update()
{
    //set variables
    [...]

    //Start AcquireFrame-ReleaseFrame loop
    while (senseManager.AcquireFrame(true) >= pxcmStatus.PXCM_STATUS_NO_ERROR)
    [...]

        //Control vJoy
        ControlJoystick([...]);

        ///Update UI
        Render([...]);

        //Release the colour frame
        [...]

    }
}

//Buttons activated or not activated (switch 1 and switch 2)
private void ControlJoystick(bool buttonState, bool buttonState2)[...]


//Render GUI
private void Render([...])
{
    [...]
        //Update UI Controls
        [...]
        {
        //Update bitmap image
        [...]

        //Update the data labels
        [...]

        //If there is an error - 'face occluded' or 'face out of frame' = turn border and alert label red
        if (trackingError == true)
        {
            [...]

        }

        //If there is an error - 'face lost' = turn border and alert label orange
        else if (faceLost == true)[...]

        //If there is no error = turn border and alert label green
        else
        {
            [...]
        }

        if (pause == false)
        {
            //If switch is activated - show aqua label displaying 'switch' to give feedback to user
            [...]
        }

        //If user pauses camera - show paused label in red and red border
        else[...]


    }));

    }
}
//Create bitmap image video stream
private BitmapImage ConvertBitmap(Bitmap bitmap)[...]


private void Shutdown()
{
    //stop the Update thread
    [...]
    //dispose realsense objects
    [...]
    //stop vjoy
    [...]
}
```

```
                //If user pauses camera - show paused label in red and red border
                else[...]


            }));

        }
    }
    //Create bitmap image video stream
    private BitmapImage ConvertBitmap(Bitmap bitmap)[...]


    private void Shutdown()
    {
        //stop the Update thread
        [...]
        //dispose realsense objects
        [...]
        //stop vjoy
        [...]
    }


    // If user clicks on 'home' button on context menu of taskbar icon - open FaceTracker home window
    private void Home_Click(object sender, RoutedEventArgs e)[...]

    // If user clicks on 'pause' button on context menu of taskbar icon - pause FaceTracker and vice versa for 'start' button
    private void Pause_Click(object sender, RoutedEventArgs e)[...]

    // If user clicks on 'quit' button on context menu of taskbar icon shutdown application
    private void Exit_Click(object sender, RoutedEventArgs e)[...]

    // If user clicks exit button on window - close window but do not close application.
    protected override void OnClosing(System.ComponentModel.CancelEventArgs e)[...]

    //If shortcut key pressed - change between video tab of 'widget' window and non-video tab
    private void Widget_Executed(object sender, ExecutedRoutedEventArgs e)[...]

    //If shortcut key pressed - open 'settings' window of FaceTracker
    private void Settings_Executed(object sender, ExecutedRoutedEventArgs e)[...]

    //If shortcut key pressed - open 'change user' window of FaceTracker
    private void ChangeUser_Executed(object sender, ExecutedRoutedEventArgs e)[...]

    //If shortcut key pressed - shutdown FaceTracker application
    private void Quit_Executed(object sender, ExecutedRoutedEventArgs e)[...]

    //Enable shortcut key command bindings to execute
    private void Action_CanExecute(object sender, CanExecuteRoutedEventArgs e)[...]

    //Make window focused
    private void facetracker_Loaded(object sender, RoutedEventArgs e)[...]


    }

}
```

7.2. Appendix B - Ethics Approval Letter, Information Sheet and Consent Form

Women's & Children's Hospital

Research Secretariat
Level 2, Samuel Way Building
72 King William Road
North Adelaide SA 5006
Tel 08 8161 6390
Tel 08 8161 6521
www.wch.sa.gov.au

9th August 2017

Dr Toan Nguyen
Senior Rehabilitation Engineer/ Research Officer
Knowledge & Innovation
Novita Children's Services
171 Days Road
REGENCY PARK SA 5010

Dear Toan

Re: Assessing the usability and utility of a new facial tracking system, called FaceTracker, with users with complex needs - a pilot trial. HREC/17/WCHN/096.
HREC expiry: 31/8/20

Thank you for your email dated 1st August 2017 in response to matters raised following the expedited review of the above Low and Negligible Risk application by the Chair and two members of the WCHN HREC. I am pleased to advise that the application has been granted full ethics approval and meets the requirements of the *National Statement on Ethical Conduct in Human Research*.

Specifically, the following documents have been noted/approved:

Document	*Version*	*Date*
Research Protocol: The study Protocol	1	14 June 2017
Letter of invitation to participant: Children version	1	14 June 2017
Letter of invitation to participant: Adult version	1	14 June 2017
Questionnaire/s: The Novita Switch Access Solutions Assessment Form		14 June 2017
Novita Consent to use Photo , Video, Audio or other Information Form	1	14 June 2017
Application LNR	AU/15/25AE219	14 June 2017
Novita RPSC knowledge & innovation project agreement		31 July 2017
Record keeping for charities		
Communication for Novita OT Staff	1	
Consent Form: Adult		
Participant Information Sheet Adults	2	
Questionnaire/s: FaceTracker Utility Questionnaire	2	
Consent Form: Children	2	
Participant Information Sheet: Children	2	

The Committee has approved the study on the understanding that it does not involve any WCHN patients or staff and that the research is not carried out at any SA Health site. This letter therefore constitutes advice on ethical consideration only. All research governance matters, including indemnification, are the responsibility of Novita and it is recommended that you obtain appropriate governance approval from Novita before proceeding. If the study is amended to include the WCHN or any SA Health site, separate authorisation from the Chief Executive or delegate of that site must be obtained through a Site Specific Assessment (SSA) request. For information on this process at the WCHN, please contact the WCHN Research Governance Officer, Ms Camilla Liddy (telephone 8161 6688, email camilla.liddy@health.sa.gov.au).

Government of South Australia
SA Health

I remind you approval is given subject to:

•immediate notification of any serious or unexpected adverse events to participants;

•immediate notification of any unforeseen events that might affect continued ethical acceptability of the project;

•submission of any proposed changes to the original protocol. Changes must be approved by the Committee before they are implemented;

•immediate advice, giving reasons, if the protocol is discontinued before its completion;

•submission of an annual report on the progress of the study, and a final report when it is completed to the WCHN Research Governance Officer. It is your responsibility to provide these reports, without reminder. The proforma for the report may be found on the WCHN Research Governance and Ethics website.

Approval is given for three years only. If the study is more prolonged than this, an extension request should be submitted unless there are significant modifications, in which case a new submission may be required. Please note the expiry date in the title above and include it in any future communications.

Yours sincerely

TAMARA ZUTLEVICS (DR)
CHAIR
WCHN HUMAN RESEARCH ETHICS COMMITTEE

INFORMATION SHEET
FOR ADULT PARTICIPANTS

novita children's services

"Assessing the usability and utility of a new facial tracking system, called FaceTracker, with users with complex needs - a pilot trial"

YOU ARE INVITED TO TAKE PART IN THIS STUDY

What is this study about?

The study involves the trial of a new computer access switching method which consists of an application that creates an interface between an Intel 3D camera and switch scanning software such as Smartbox's Grid 3. The system allows for a purposeful facial expression (e.g. mouth open) produced by the user to be detected as a switch press. The reason for undertaking this project is to provide a potential alternative for users with severe physical disabilities who have limitations in their abilities to use other access technologies for communication, computer access and or environmental control. The intention and anticipated outcome of this project is to provide sufficient trialling of the prototype system so that the developed switching system can be proven effective and become commercially available on the market.

Who is doing the study?

A Flinders University Biomedical Engineering, Miss Leonie Rich-Perrett, is working on the design, development and trial of version 1 of this computer access switching method for her Masters thesis project in 2017. A fourth year Flinders University student will further develop and trial version 2 of the system towards the end of 2017 as part of her work-placement at Novita. Both students are working in collaboration and under the supervision of a Senior Occupational Therapist - Annabelle Tilbrook and a Senior Rehabilitation Engineer/ Research Officer- Dr Toan Nguyen, to conduct the research. Funding for the study is provided by Novita and Flinders University.

What does participation in the study involve?

- You will be asked to attend 1 trial session at no cost to you. The session will take up to 2 hours. If necessary, the trial will be broken down into 2 separate sessions e.g. if client factors limit ability to participate over longer timeframes.
  The Flinders University student, Senior Rehabilitation Engineer, Senior Occupational Therapist (OT) and an Allied Health Assistant will be present for the session. Your regular OT may be present if necessary. Photos of the switching setup of you will be taken during the session as part of the trial. This will ensure that there would be adequate detail for any future training, re-assessing progress or to provide a final set up solution for you.
- During the session, you will be asked to do one or more switching activities they are familiar with for 20 – 30 minutes.
- The session will be videotaped using 2 cameras.
- The video footage will be used for analysis of the systems performance to allow for future improvements to be made.
- The interaction with the 3D video camera will be recorded by the system to assist with the refinement of the prototype
- You will also be asked to fill out a short questionnaire following the trial to provide feedback on the usefulness and ease of using the system.

How can the trial help you?

- You may benefit from the project by being able to trial a new and innovative computer access switching system that could potentially be an option for you in the future to help you reach personal goals that are not possible for you using current technology options. This could be for communication, play, learning/education or control of the environment.

Appendix 2: FaceTracker Project_InformationSheet_Adult_Version 2

What happens with the technology after the trial?

- Your trial of this new computer access switching method and your feedback will assist in improving the effectiveness of the system. After further refinement it will be made available for purchase.

Are there any risks?

- We believe that the only potential risk of this pilot trial is that the system requires repetitive facial feature movements for operation which may result in joint (e.g. jaw) and muscle soreness or fatigue if performed excessively for long periods of time. However, as the trial sessions are short there is very low likelihood of this and it is not a risk level higher than what they may have been exposed to through trialling other computer access devices.
- The tasks your child will complete with the prototype switching system will not be any different to the tasks they would normally undertake in their OT sessions.
- An OT will be present at all times to monitor your child. Depending on the facial expression used by the individual tester, strategies will be put in place to minimise fatigue and/or discomfort. For example, your child will be asked to indicate any discomfort during trialling and to use methods such as the rest/pause regime or switching between different modes of facial expressions to minimise this.
- You may feel uneasy with unfamiliar staff during the trial but as your OT will be present (if needed) we hope that this will be minimal.

Can I withdraw from the study?

Participation in the study is completely voluntary (your choice). You are not under any obligation to take part and can withdraw from the study at any time without affecting the services you receive from Novita.

Will anyone else know the results of the study?

The trial information collected during the study will be included in your client file held at Novita and will only be available to Novita staff and members of the research team. This will help your OT to plan further therapy for you.
Results for all participants will be combined when reporting results of the study. You will not be identified in any publications or other documents that arise from the study.

Will I be able to find out the results of the study?

A summary of results will be sent to all participants at the end of the study.

I want to participate! How do I sign up?

If you choose to participate and agree to be part of the study after reading this information sheet, please complete the enclosed consent form and return it using the pre-paid envelope provided.

If needed, we may call you in one week to talk to you about the study.

IF YOU WANT TO KNOW MORE, PLEASE CONTACT THE RESEARCH TEAM:

Mrs Annabelle Tilbrook
Occupational therapist
annabelle.tilbrook@novita.org.au
Ph: 8349 2023

Dr Toan Nguyen
Rehabilitation Engineer/ Research Officer
toan.nguyen@novita.org.au
Ph: 8243 8303

This research project has been given approval by the Women's & Children's Health Network Human Research Ethics Committee. The Committee's Secretary, Ms Brenda Penny can be contacted on 08 8161 6521 if you wish to discuss the approval process or have any concerns or complaints.

Appendix 2: FaceTracker Project_InformationSheet_Adult_Version 2 novita children's services

CONSENT FORM

Participation in study

Study Title: "Assessing the usability and utility of a new facial tracking system, called FaceTracker, with users with complex needs - a pilot trial"

Principal Investigator: Dr Toan Nguyen

I ....*(the parent/guardian)* have read and understood the information provided in the information sheet. I have had a chance to discuss this study and I am satisfied with the answers I have been given.

- I understand that taking part in this study is voluntary at no cost to me and that I may withdraw from the study at any time, and this will in no way affect my child's current or future care at Novita.
- I know who to contact should I have any questions about the study.
- I agree that my child nominated below may participate in the trial.
- I understand that the trials may take up to 2 hours and if necessary, the trial will be broken down into 2 separate sessions, and that the trial will be videotaped for analysis of the switching method performance.
- I understand that my child's interaction with the 3D video camera will be recorded by the system to assist with the refinement of the prototype.
- I understand that my child and I will be asked to fill out a questionnaire following the completion of the trial, to provide feedback to the research team.
- I understand that the information collected from the trial will be securely stored at Novita.
- I understand that research data collected for this study may be shared with members of the study team external to Novita, but that my child or I will not be identified in any way.
- I understand that photos will be taken of my child's position, switching and mount set up as part of the trial. These photos will be securely stored in your child's file at Novita and will only be available to Novita staff and the research team.
- I am aware that I should retain a copy of the Consent Form, when completed, and the Information Sheet.

Note: The names of the contact person are on the Information Sheet if you have any questions.

NAME OF PARENT/GUARDIAN: ....

SIGNATURE ....DATE: ....

NAME OF CHILD ....

My child has given consent to participate ☐ Yes ☐ No ☐ N/A

SIGNATURE OF PRINCIPAL INVESTIGATOR: ....DATE: ....

Appendix 3: FaceTracker Project_Consent Form_Children_Version 2

INFORMATION SHEET
FOR CHILDREN PARTICIPANTS

"Assessing the usability and utility of a new facial tracking system, called FaceTracker, with users with complex needs - a pilot trial"

YOUR CHILD IS INVITED TO TAKE PART IN THIS STUDY

What is this study about?

The study involves the trial of a new computer access switching method which consists of an application that creates an interface between an Intel 3D camera and switch scanning software such as Smartbox's Grid 3. The system allows for a purposeful facial expression (e.g. mouth open) produced by the user to be detected as a switch press. The reason for undertaking this project is to provide a potential alternative for users with severe physical disabilities who have limitations in their abilities to use other access technologies for communication, computer access and or environmental control. The intention and anticipated outcome of this project is to provide sufficient trialling of the prototype system so that the developed switching system can be proven effective and become commercially available on the market.

Who is doing the study?

A Flinders University Biomedical Engineering, Miss Leonie Rich-Perrett, is working on the design, development and trial of version 1 of this computer access switching method for her Masters thesis project in 2017. A fourth year Flinders University student will develop and trial version 2 of the system towards the end of 2017 as part of her work-placement at Novita. Both students are working in collaboration and under the supervision of a with Senior Occupational Therapist - Annabelle Tilbrook and Senior Rehabilitation Engineer/ Research Officer- Dr Toan Nguyen, to conduct the research. Funding for the study is provided by Novita and Flinders University.

What does participation in the study involve?

- You will be asked to attend 1 trial session with your child at no cost to you. The session will take up to 2 hours. If necessary, the trial will be broken down into 2 separate sessions e.g. if client factors limit ability to participate over longer timeframes. The Flinders University student, Senior Rehabilitation Engineer, a Novita Occupational Therapist (OT) and an Allied Health Assistant will be present for the session. Your regular OT may be present if necessary.
- Photos of the switching setup of your child will be taken during the session as part of the trial. This will ensure that there would be adequate detail for any future training, re-assessing progress or to provide a final set up solution for the child.
- During the session, your child will be asked to do one or more switching activities they are familiar with for 20 – 30 minutes.
- The session will be videotaped using 2 cameras.
- The video footage will be used for analysis of the systems performance to allow for future improvements to be made.
- The interaction with the 3D video camera will be recorded by the system to assist with the refinement of the prototype
- You and your child will also be asked to fill out a short questionnaire following the trial to provide feedback on the usefulness and ease of using the system.

How can the trial help my child?

- Your child may benefit from the project by being able to trial a new and innovative computer access switching system that could potentially be an option for them in the future to help them reach personal goals that are not possible for them using current technology options. This could be for communication, play, learning/education or control of their environment.

Appendix 1: FaceTracker Project_InformationSheet_Children_Version 2

What happens with the technology after the trial?

- Your child's trial of this new computer access switching method and your feedback will assist in improving the effectiveness of the system. After further refinement it will be made available for purchase.

Are there any risks?

- We believe that the only potential risk of this pilot trial is that the system requires repetitive facial feature movements for operation which may result in joint (e.g. jaw) and muscle soreness or fatigue if performed excessively for long periods of time. However, as the trial sessions are short there is very low likelihood of this and it is not a risk level higher than what they may have been exposed to through trialling other computer access devices.
- The tasks your child will complete with the prototype switching system will not be any different to the tasks they would normally undertake in their OT sessions.
- An OT will be present at all times to monitor your child. Depending on the facial expression used by the individual tester, strategies will be put in place to minimise fatigue and/or discomfort. For example, your child will be asked to indicate any discomfort during trialling and to use methods such as the rest/pause regime or switching between different modes of facial expressions to minimise this.
- Your child may feel uneasy with unfamiliar staff during the trial but as you will be present, we hope that this will be minimal.

Can I withdraw from the study?

Participation in the study is completely voluntary (your choice). You are not under any obligation to take part and can withdraw from the study at any time without affecting the services you and your child receive from Novita.

Will anyone else know the results of the study?

The trial information collected during the study will be included in your child's client file held at Novita and will only be available to Novita staff and members of the research team. This will help your OT to plan further therapy for your child.
Results for all participants will be combined when reporting results of the study. You and your child will not be identified in any publications or other documents that arise from the study.

Will I be able to find out the results of the study?

A summary of results will be sent to all participants at the end of the study.

I want to participate! How do I sign up?

If you choose to participate and agree for your child to be part of the study after reading this information sheet, please complete the enclosed consent form and return it using the pre-paid envelope provided.

If needed, we may call you in one week to talk to you about the study.

IF YOU WANT TO KNOW MORE, PLEASE CONTACT THE RESEARCH TEAM:

Mrs Annabelle Tilbrook
Occupational therapist
annabelle.tilbrook@novita.org.au
Ph: 8349 2023

Dr Toan Nguyen
Rehabilitation Engineer/ Research Officer
toan.nguyen@novita.org.au
Ph: 8243 8303

This research project has been given approval by the Women's & Children's Health Network Human Research Ethics Committee. The Committee's Secretary, Ms Brenda Penny can be contacted on 08 8161 6521 if you wish to discuss the approval process or have any concerns or complaints.

Appendix 1: FaceTracker Project_InformationSheet_Children_Version 2

7.3. Appendix C - NSASA raw data

Performance Skills	EK Current Score	EK FaceTracker Score	RE Current Score	RE FaceTracker Score	JA Current Score	JA FaceTracker Score
			Motor Skills			
1.1 Fluid movements on approach to switch	2	3	3	4	3	4
1.2 Accurately contacts switch.	3	3	4	3	2	4
1.3 Applies appropriate force to switch	2	3	4	3	3	3
1.4 Accurately releases switch	4	4	4	4	4	4
1.5 Maintains functional position	2	2	4	4	4	4
1.6 Endures to complete activity.	2	3	4	4	4	4
			Visual Skills			
2.1 Looks at and focuses on visual target	4	4	4	4	4	4
2.2 Visually tracks or scans or gaze shifts	4	4	4	4	4	4
			Process Skills			
3.1 Attends to activity	4	4	4	4	4	4
3.2 Understands purpose/goal	4	4	4	4	4	4
3.3 Appropriate use of switch	4	4	4	4	4	4
3.4 Starts activity independently	4	4	4	4	4	4
3.5 Sequences activity logically	4	4	4	4	4	4
3.6 Responds to cues	4	4	4	4	4	4
3.7 Problem solves when errors or problems occur	4	4	4	4	4	4
3.8 Ends activity at appropriate time	4	4	4	4	4	4

7.4. Appendix D – Questionnaire

FaceTracker Utility Questionnaire

Name:

Current Computer Access Method:

This questionnaire is largely based on guidelines of the International Standards Organisation (ISO) 9241- 411: 2012 (Ergonomics of human-system interaction – Part 411: evaluation methods for the design of physical input devices; Table C.1 - Independent rating scale). Some adjustments have been made that are more specific to the non-contact FaceTracker system.

PART ONE: User comfort/feelings of system performance

Please rate the following:

1. Force required for actuation						
1	2	3	4	5	6	7
Very uncomfortable				Very comfortable		
2. Smoothness during operation						
1	2	3	4	5	6	7
Very rough				Very smooth		
3. Effort required for operation						
1	2	3	4	5	6	7
Very high				Very low		
4. Accuracy						
1	2	3	4	5	6	7
Very inaccurate				Very accurate		
5. Operation speed						
1	2	3	4	5	6	7
Unacceptable				Acceptable		
6. General comfort						
1	2	3	4	5	6	7
Very uncomfortable				Very comfortable		
7. Overall operation of input device						
1	2	3	4	5	6	7
Very difficult (to use)				Very easy (to use)		
8. Jaw Fatigue						
1	2	3	4	5	6	7
Very high				None		
9. Neck Fatigue						
1	2	3	4	5	6	7
Very high				None		
10. General Fatigue (mental/physical tiredness)						
1	2	3	4	5	6	7
Very high				None		
11. Any other Fatigue, please specify:						
1	2	3	4	5	6	7
Very high				None		

PART TWO: User satisfaction/feedback:

1. What do you like or don't like about the FaceTracker computer access?
2. Do you have any other suggestions for improvement to the system?
3. Do you think the system would be useable in the environments that you would need to operate it in? Why?

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