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Eye tracking of pilots during approach and landing on unprepared and prepared runways

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EYE TRACKING OF PILOTS DURING APPROACH AND LANDING ON UNPREPARED AND PREPARED RUNWAYS

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Masters of Science in Engineering.

Johannesburg, 2018

DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the degree of Master of Science in Engineering at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

_____

(Jadine Inkley)

24 August 2018

ABSTRACT

There are more airfields in South Africa that have unprepared runways than prepared runways and therefore pilots and airlines operated in South Africa would benefit from aircraft being designed to land on both runway types. Therefore, the purpose of this report was to determine whether there was a difference between eye movements of pilots during approach and landing on prepared and unprepared runways, to understand if cockpit layout should change to best suit landing capabilities. A study was conducted in the Embraer ERJ-145 flight simulator with 10 certified airline pilots. The pilots wore eye tracking glasses while completing their training sessions. The eye tracking data was recorded during the approach and landings of these sessions and the data was analysed using SMI BeGaze™ software. These results were exported to Microsoft Excel™ and GraphPad Prism™ to complete statistical analysis. The results showed that the Primary Function Display (PFD) was the most favoured Area of Interest (AOI) by the pilots. The mean dwell time, percentage dwell time and fixation count were all highest in the PFD. The differences between the prepared and unprepared runway approaches and landings were minimal for mean dwell time, percentage dwell time and fixation count, however, the fixation rate increased for all AOIs during unprepared runway approaches and landings. Also, the transition between AOI's showed that a pilot increased number of transitions between the windscreen (OUT) and the PFD during unprepared runway landings. It was concluded that the mean dwell time, percentage dwell time and fixation count had minimal changes when landing on an unprepared runway. However, pilots tended to have a higher fixation rate when coming in to land on unprepared runways. This meant that the pilots needed more time to process the data on the instruments when flying an unfamiliar scenario (such as the unprepared runway landing). The number of transitions between the PFD and Outside (OUT) AOIs led to the recommendation that aircraft that are designed to land on both runway types should include a Heads-Up Display (HUD) to reduce pilot workload by projecting the PFD on the windscreen.

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CONTENTS

DECLARATION II

ABSTRACT III

ACKNOWLEDGEMENTS IV

LIST OF FIGURES VIII

LIST OF TABLES IX

NOMENCLATURE X

1 INTRODUCTION 1

1.1. Background and motivation 1

1.2. Purpose of the Study 1

1.3. Contribution 1

2 LITERATURE SURVEY 2

2.1. Runway Types and Effects on Aircraft Design 2

2.2. Approach and Landing 2

2.3. Situational Awareness and Eye-tracking 3

2.4. Eye Tracking Measurements and Parameters 4

2.5. Eye tracking glasses 5

2.6. Eye-Tracking Applications 6

2.7. Eye tracking and situational awareness studies within aviation 6

2.8. Cockpit Instrumentation Layout 8

3 RESEARCH QUESTION 12

3.1. Development of Research Question 12

3.2. Research Question 12

3.3. Critical Research Question 12

4 RESEARCH OBJECTIVES 13

4.1. Objectives 13
5 RESEARCH METHODS 14
5.1. Sample size calculation 14
5.2. Method Followed 15
5.3. Ethical considerations 18
5.4. Study details 18
5.5. Examples of Video Data 20
6 RESULTS 23
6.1. Validation of Data 23
6.2. Mean Dwell Time per AOI visit 24
6.3. Percentage Dwell Time 26
6.4. Fixation Count 28
6.5. Fixation Rate 29
6.6. AOI Transition Matrix 30
6.7. Further Observations 32
7 DISCUSSION 33
7.1. Limitations 33
7.2. AOI order of importance 33
7.3. Mean Dwell Time per AOI visit 34
7.4. Percentage Dwell time 35
7.5. Fixation Count 35
7.6. Fixation Rate 36
7.7. AOI Transition Matrix 36
7.8. General Discussion 37
8 CONCLUSIONS 38

9 RECOMMENDATIONS 39
9.1. Heads-Up Display (HUD) 39
9.2. Pilot and Instructor Training 39
9.3. Further Studies 39
REFERENCES 40
A. APPENDIX A – SMI® EYE TRACKING GLASSES SPECIFICATIONS [40] 45
B. APPENDIX B – EMBRAER E145 COCKPIT PANELS [41] 46
C. APPENDIX C – PARTICIPANT INFORMATION SHEET 50
D. APPENDIX D – LETTER OF CONSENT 51
E. APPENDIX E – VALIDATION OF DATA 52
E.1 Prepared Runway Approach and Landing 52
E.2 Unprepared Runway Approach and Landing 55

LIST OF FIGURES

Figure 2-1: Comparison between prepared and unprepared runways. 2
Figure 2-2: Diagram showing the approach and landing phases of flight [6]. 3
Figure 2-3: Eye tracking device used in Anders' (2001) study [13] 5
Figure 2-4: SMI Eye Tracking Glasses [14] 6
Figure 2-5: Airbus A319 Conventional (Analogue) Cockpit [35], showing the outline of the "T-shape" layout. 9
Figure 2-6: Airbus A319 glass cockpit [35] 10
Figure 2-7: Head-up display in a Boeing 737-800 [37]. 11
Figure 5-1: Embraer ERJ-145 Simulator, showing calibration points. [39] 16
Figure 5-2: Allocated AOI's in ERJ-145 Simulator Cockpit. Picture [39] 17
Figure 5-3: Pilot experience shown in total number of flying hours, number of flying hours in the ERJ-145 and number of flying hours in the ERJ-145 simulator. 19
Figure 5-4: Number of prepared and unprepared runway landings performed by each pilot. 19
Figure 5-5: Screenshot of visual pattern of pilot during approach on prepared runway. 21
Figure 5-6: Screenshot of visual pattern of pilot during approach on prepared runway, showing runway. 21
Figure 5-7: Screenshot of visual pattern of pilot during approach on unprepared runway. 22
Figure 5-8: Screenshot of visual pattern of pilot during approach on unprepared runway, showing runway. 22
Figure 6-1: Mean dwell times for prepared and unprepared runway landings per AOI 25
Figure 6-2: Number of revisits per AOI for prepared and unprepared runway landings. 25
Figure 6-3: Percentage dwell times per AOI for prepared and unprepared runway landings 27
Figure 6-4: Fixation Count per AOI for prepared and unprepared runway landings. 28
Figure 6-5: Fixation rate per AOI for prepared and unprepared runway landings. 30

LIST OF TABLES

Table 6-1: Mean Dwell Time per AOI visit Bonferroni's multiple comparison data..... 26
Table 6-2: Percentage dwell time Bonferroni's multiple comparison data..... 27
Table 6-3: Fixation count Bonferroni's multiple comparison data. 29
Table 6-4: Prepared Runway AOI Transition Matrix..... 31
Table 6-5: Unprepared Runway AOI Transition Matrix. 31

NOMENCLATURE

AOI	-	Area of Interest
CAA	-	Civil Aviation Authority
CC	-	Centre Console
EICAS	-	Engine Indication and Crew Alerting System
ERJ	-	Embraer Regional Jet
FOD	-	Foreign Object Debris
HUD	-	Heads-Up Display
ND	-	Navigational Display
OP	-	Overhead Panel
OUT	-	Outside
PFD	-	Primary Function Display
SD	-	Standard Deviation
SMI	-	SensoMotoric Instruments

1 INTRODUCTION

1.1. Background and motivation

The majority of commercial aircraft are designed to operate from prepared runways [1]. In an African context there are significantly more airfields with unprepared runways than prepared runways [2] and therefore pilots and airlines operated in Africa would benefit from aircraft being designed with the capability to land on both. To do this, cockpit instrument panels may need to be ergonomically designed to make the pilot's job easier and safer when landing on unprepared runways. Ergonomics refers to the man-machine interface and how simple it is to work with. The purpose of designing ergonomically is to ensure that the pilot's workload is reduced by creating an interface that positions the most commonly used instruments in his/her field of view so that he/she does not need to make drastic eye or head movements in order to read or reach the instruments. This study will attempt to understand how the eye and head movements of pilots differ when landing on the different runway types, serving as design parameters for future cockpit layouts and possible future training techniques.

1.2. Purpose of the Study

The purpose of this study is to identify whether there is a difference between eye movements of pilots during approach and landing on prepared and unprepared runways.

1.3. Contribution

The intention of this study was to determine whether the design of the cockpit layout should change depending if the aircraft has been designed to land on unprepared runways. In the case that more of the pilot's time is spent looking outside the windshield then a possible head-up display (HUD) would be better suited for unprepared runway landings.

2 LITERATURE SURVEY

2.1. Runway Types and Effects on Aircraft Design

There are two main types of runways, prepared and unprepared. Prepared runways refer to runways surfaced with asphalt or concrete, these usually have runway markings (painted lines) and landing lights. Unprepared or semi-prepared runways typically refer to gravel or grass surfaces [1] and generally don't have markings or landing lights.



Figure 2-1: Comparison between prepared and unprepared runways. 1 - Prepared runway at Dubai International Airport with visible markings and landing lights [3]. 2 - Unprepared runway in Belize showing no markings and lights [4].

Most commercial passenger aircraft are designed to solely land on prepared runways [1]. Unprepared runway landings/take-offs would require that the design of the aircraft include the following considerations:

- Low pressure tyres and robust braking systems due to harder, "bumpier" and higher friction landings [5].
- Engines need to be placed higher off the ground to reduce the risk of foreign object debris (FOD) damaging the engines [6].

Further design considerations may include cockpit layout and instrument arrangement.

2.2. Approach and Landing

The approach and landing are the two final phases of flight (Figure 2-2). These are also the most demanding phases of flight, in terms of pilot workload [7]. Before the pilots start the approach, they perform an approach briefing. The briefing covers the chosen airport, runway and expected taxi route, as well as any special instructions given to the

crew from the airport. The crew enter the approach at a specific altitude and speed, they try to keep to this as they come in to land to ensure a stabilised approach [7].

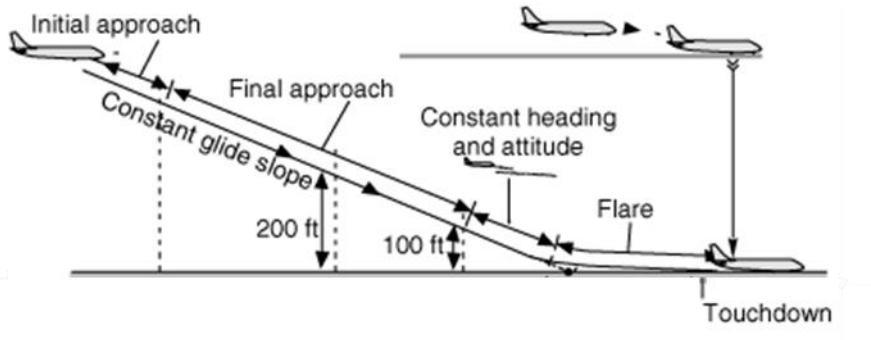


Figure 2-2: Diagram showing the approach and landing phases of flight [8].

2.3. Situational Awareness and Eye-tracking

Endsley [9] defines situational awareness as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (p.36). Furthermore, Endsley defines situational awareness as having three levels; perception, comprehension and projection. Perception refers to how the pilot notices the onset of the situation; comprehension refers to how the pilot interprets the situation; and projection refers to the pilot's prediction on the consequences of the situation [10].

To study situational awareness, it is necessary to understand where a person focuses and what they perceive in their surroundings while in a particular situation. Situational awareness is the foundation of decision-making, especially in highly stressful, complex and demanding circumstances [9]. The function of a pilot is to absorb situational information and react appropriately. Even with smart systems, the pilot is still a vital part of the information processing loop, as the pilot is trained to make fast, calculated decisions based on the information around him/her. An effective way of understanding situational awareness is by studying eye and head movements. This can be done by using eye-tracking devices while the person is in their respective environment.

Studying eye movements allows the tracking of a subject's main visual focus, which leads to understanding certain decision-making processes. Eye tracking must be

accompanied by head tracking as the two motions are usually coincident. Eye tracking using eye tracking glasses is still a new field of research and has proven to be useful for many applications [11].

2.4. Eye Tracking Measurements and Parameters

The main parameters that are of interest while studying eye tracking are saccades, dwell times and fixations and these are measured within specified areas of interest [12].

Area of Interest (AOI) – a user/researcher defined area within the field of view of the study. This area's size and location is determined by the user/researcher to best fit the purpose of the study [13]. Areas of interest for pilots would be the instruments and equipment surrounding them in the cockpit as well as the view outside the windscreen.

Fixation – A duration in which the eye has stopped moving in order for the subject to read or view something. A fixation is determined by a duration that usually ranges between 40ms to 800ms [14]. A pilot would fixate on an instrument when gathering information from that instrument.

Dwell – A group of fixations on a specific AOI [14]. A dwell is longer than a fixation (>800ms) and would represent the reading of an instrument within the cockpit.

Saccade – Rapid eye movements between dwell or fixation points [14]. When a pilot moves his eyes to look at another instrument, the path that his eyes move is the saccade. There is no focus or fixation during a saccade.

Fixation count – Number of fixations on an AOI during the trial time. This relates to the number of times a pilot will fixate on an instrument or AOI to gather information.

Dwell time – The amount of time spent reading an AOI during the trial time. This relates to the total time a pilot dwells on a particular instrument or AOI.

Revisit – Number of times the viewer views an AOI again within a trial time. The pilot may revisit the compass 3 times during the trial, this means that he/she has viewed the compass 4 times within the trial time.

Depending on the time spent and number of times a subject spends doing each of these activities one can determine what the subject is fixating on or whether they just scan over it

2.5. Eye tracking glasses

Eye tracking glasses are designed with a minimum of three cameras, two facing the subject's eyes and the other facing outward at what the subject is seeing. The glasses measure both eye and head movements simultaneously by recording the pilot's view and overlaying what the pilot is looking at on that view.

Eye tracking glasses are more versatile (especially when wireless) than previous eye and head tracking equipment (see Figure 2-3) as the subject is not restricted in head or neck movements. Generally, glasses (see Figure 2-4) are more comfortable and less invasive, this makes studies easier to carry out and the results are more accurate as the participant is less likely to be aware of the device during the experiment.

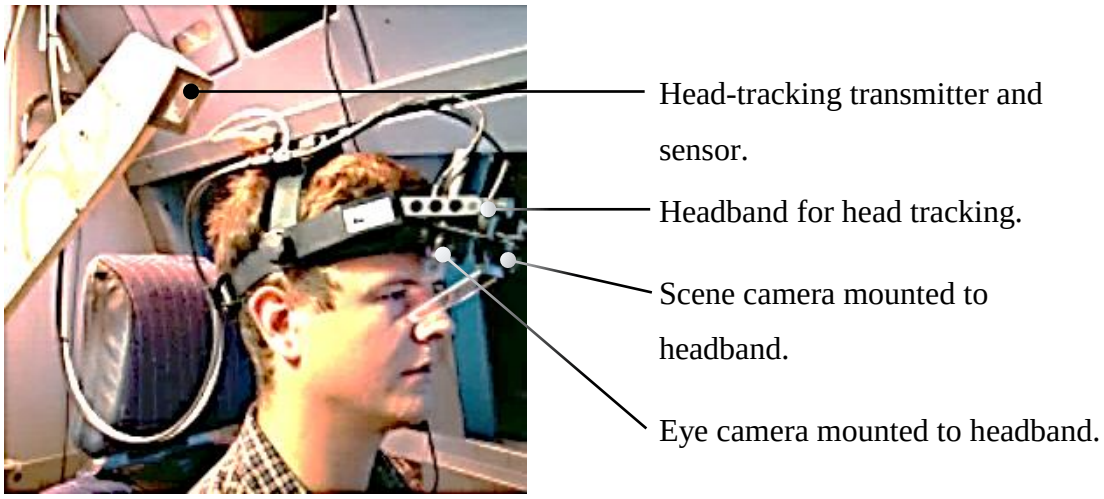


Figure 2-3: Eye tracking device used in Anders' (2001) study [15]



Figure 2-4: SMI Eye Tracking Glasses [16]

2.6. Eye-Tracking Applications

Eye movement monitoring allows a researcher to delve into a subject's cognitive state (or state of mind) and decision-making processes [14], and because of this, eye tracking has been used to study many human applications/interfaces including:

- Enhancing clinical observations and interpretation in occupational therapy [17] [18]
- Understanding readers' visual interactions with a newspaper [19]
- Eye movement patterns in schizophrenia patients [20]
- Helping paraplegics or people with multiple sclerosis to use their eyes to communicate through a computer [21]
- Understanding how people read subtitles, in their home language or in another language [22].

These are just a few situations in which eye tracking has been used. To narrow this down, only aviation eye-tracking studies were identified.

2.7. Eye tracking and situational awareness studies within aviation

By analysing eye movements within the cockpit, a researcher can identify the mental workload and cognitive capacity of pilots [14]. Mental workload refers to the amount of information a pilot needs to *process* in order to respond in a given situation [23],

whereas cognitive capacity refers to the amount of information a pilot is able to *retain* at a particular time [24]. This allows the researcher to understand how the pilot processes information while flying and during different flight situations. Extensive studies have been done on pilot eye tracking during flight. Some of these studies only look at eye movements during normal flight to understand usual pilot behaviour [15] [25] [26]. This was further extended to the introduction of emergencies or failures during flight [27] [28], traffic scanning [29] [30] [31] and also to determine the differences in eye movements between novice and expert pilots [32] [33].

Anders [15] conducted an eye tracking study titled "Pilots' attention allocation during approach and landing". He completed this study in an A330 full flight simulator and used eye and head tracking devices to measure the monitoring behaviour of 16 airline pilots. The situation that the pilots were measured on was their eye movements during approach and landing. The A330 is a fly-by-wire aircraft, meaning that a lot of the flight plan is completed before the flight and entered into the flight computer, then automation monitors it during the flight, this reduces workload during normal flight.

Wickens [31] and Colvin [30] completed a similar study using eye tracking to show the effectiveness of pilots' visual traffic scanning techniques. In Wickens' study, seventeen pilots volunteered to participate. Each pilot flew six 70-minute cross country flights and their eye and head movements were only monitored in the last four flights for each pilot [31]. In Colvin's study, five participants (FAA instrument rated pilots) were required to fly a 45-minute Visual Flight Rule (VFR) cross-country flight in an area that the pilots were unfamiliar with. This ensured that the participants would keep a constant eye out for air traffic [30].

Van de Merwe [25] used eye-tracking to study pilot "eye movements as an indicator of situational awareness". This was achieved by testing 12 airline pilots during the introduction of a fuel leak malfunction without the pilots knowing the nature of the malfunction.

All these studies were conducted in full flight simulators with qualified pilots and all used both eye and head tracking equipment. Wickens concluded that on average the pilots spent 60% of their time focusing on the instrument panel and 40% of their time

scanning [31]. Colvin's conclusion differed from Winkens' in that his pilots all showed varying differences in time allocation outside and inside the cockpit [30]. Van de Merwe's study established that the participants spent most of their time on the Navigational Display (ND) and Primary Flight Display (PFD) during the normal flying period, however after the malfunction was introduced the attention was moved to the Engine Indication and Crew Alerting System (EICAS) [25].

Anders showed that the pilots' attention, during approach and landing, was allocated to the PFD 40% of the time and 18% of the time was spent on the ND [15]. Yet only 3.2% of the pilots' time was allocated to looking outside the windscreen [15].

All these studies were performed using qualified pilots in full flight simulators. Each of the researchers designed specific experiments or scenarios for their pilots to fly and all of these scenarios were based at major hubs on major flight routes. The study conducted by Anders [15] was probably the closest to this study however, all of the landings were on prepared runways and at major hubs [15]. This is probably why the pilot's allocation time outside the windscreen was only 3.2%, as the pilots were familiar with the airport they were landing at and because the runway would have had landing lights, runway lines and air traffic control (i.e. a prepared runway) to guide the pilot and aid in decision making during flight.

2.8. Cockpit Instrumentation Layout

In the early 1900's, when the first aircraft were being designed, flying was based solely on visual and control tasks [34]. The control tasks consisted of ailerons and rudder and the pilots just had to look outside to know where, how high and how fast they were flying. The evolution of flight required the pilots to monitor more while flying and to be able to fly at night or during bad weather. Therefore, slowly, more instruments were added to the cockpit [34]. Data has shown that this cockpit evolution continued up until the 1980's [35]. As the cockpit evolved, so did airport and runway design.

In the late 1940's, Fitts, Jones and Milton [36] wanted to find out what would be the best arrangement of cockpit layout. Without modern eye-tracking equipment, they used video and manually classified eye movements while flying a C-45 aircraft. And from

this study, their recommendations resulted in the well-known "T-shape" instrument layout on the instrument panel (shown in Figure 2-5) [36].

Since the 1940s, aviation displays have been upgraded to try to reduce pilot workload and job complexity (Figure 2-5 and Figure 2-6) [37]. The introduction of the glass cockpit, in the late 1980s, gave the instrument panel a cleaner, less cluttered feel. However, despite these changes, the amount of information pilots are expected to handle has not decreased, but rather increased, due to the amount of data that can be shown on the glass displays [38]. All information is present on analogue cockpits, whereas in glass cockpits some information is monitored and only displayed if requested. An analogue cockpit ensured that pilots created and memorised visual patterns for trained situations. The glass cockpit has allowed pilots to modify their instrument layout for each flying scenario, as it is a screen with multiple displays rather than a fixed instrument, therefore this could be modified to better suit landing on unprepared runway strips.

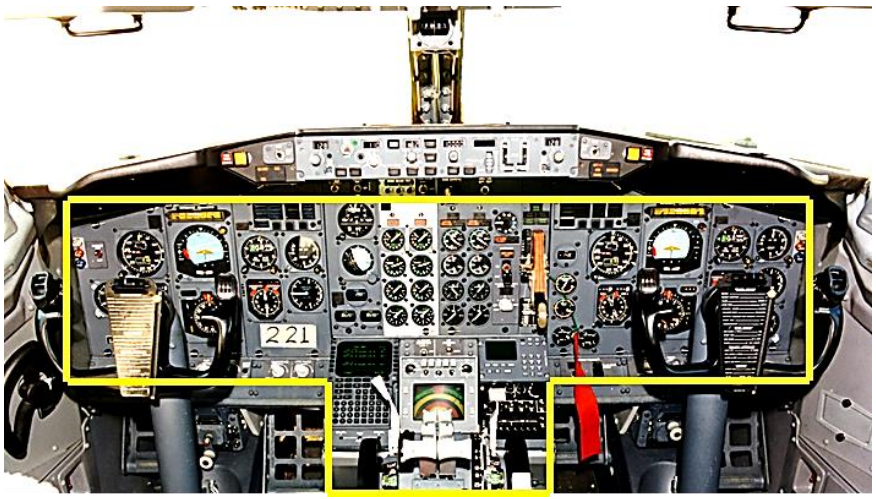


Figure 2-5: Airbus A319 Conventional (Analogue) Cockpit [39], showing the outline of the "T-shape" layout.



Figure 2-6: Airbus A319 glass cockpit [39]

An extension of the cockpit onto the windscreen known as a head-up display (HUD) was introduced in the Royal Air Force during World War II [40]. The HUD allows the pilot to have access to critical flying information while focusing outside the aircraft [41]. The image is projected on a screen in front of the windshield, as seen in Figure 2-7, so that the pilot can 'look through' the instruments to view the environment outside, thus reducing the need to move his/her eyes, or head, to look between the instrument panel and outside. The projected image displays the virtual horizon on the top, the runway aim point in the centre, the heading on the bottom, the airspeed on the left and the altitude on the right. Head-up displays were created for military aircraft, specifically fighter aircraft, as the pilot would need to see his/her vital flying controls while concentrating on looking for targets and threats [41].



Figure 2-7: Head-up display in a Boeing 737-800 [42].

There was not a lot of data found showing whether the current convention of instrument panel layout (glass cockpit) was designed with both a prepared and unprepared runway in mind. Therefore, this identifies the gap in research which leads to the research question for this project.

3 RESEARCH QUESTION

3.1. Development of Research Question

By studying pilots' eye movements while flying a "glass cockpit", one can determine where the pilots' focus is and how often their eyes fixate between instruments in the cockpit for them to fly effectively. This method could help understand where the pilot's attention allocation is while flying a glass cockpit and landing on unprepared and prepared runways.

3.2. Research Question

By monitoring pilots' eye movements during landing approaches on different runway types; would it be beneficial to change the layout of the cockpit to better suit the runway type that the aircraft would be landing on?

3.3. Critical Research Question

Do pilots spend more of their time looking outside the windscreen during unprepared runway approaches than during prepared runway approaches?

4 RESEARCH OBJECTIVES

4.1. Objectives

The following set of objectives were addressed during the course of this investigation.

1. Measure pilots' eye movements and identify which areas of interest the pilot fixates most often on during approach and landing on a prepared runway.

2. Measure pilots' eye movements and identify which areas of interest the pilot fixates most often on during approach and landing on an unprepared runway.

3. Create a model to describe the different eye movement behaviours on the different runway types.

4. To make recommendations towards future cockpit layout design.

5 RESEARCH METHODS

5.1. Sample size calculation

A sample size calculation was performed to determine the number of pilots needed to best represent the population.

According to the South African Civil Aviation Authority (CAA) there are a total of 17449 registered pilots in South Africa (as of 2014) of which 3039 are certified commercial (aeroplane) pilots [43]. The population size being studied are only pilots that are certified to fly the ERJ-145. The number of pilots that are registered in this category in South Africa could not be obtained, however, it would not make a difference to the sample size and therefore, a population size of 3039 was used.

The other parameters needed for the sample size calculation were; confidence level (corresponding Z-score) and margin of error. Using a confidence level of 95%, (Z-score = 1.96), a margin of error of 20% and a standard deviation (SD) of 0.5, the sample size calculation came out as follows:

$$Sample\ size = \frac{(Z-score)^2 \times SD(1-SD)}{(margin\ of\ error)^2}$$

$$= \frac{(1.96)^2 \times 0.5(1-0.5)}{(0.2)^2}$$

$$= 24$$

Therefore, the sample size for a 20% margin of error is 24.

In this calculation, it appears the population size is not taken into account. In order to correct for the population size the SD would need to be calculated by a correction factor $\left(\sqrt{\frac{N-n}{N-1}}\right)$, where N is the population size and n is the sample size. Using a population size of 3039 and a sample size of 24 this factor would equal 0.996. This shows that the sample size is so small compared to the population size and therefore the correction factor makes no real difference.

Due to the limitations on this investigation, only 10 pilots were able to be sourced. Using a sample size of 10, and working backwards, the margin of error on this investigation would be as follows:

$$Margin\ of\ error = \sqrt{\frac{(Z-score)^2 \times SD(1-SD)}{(Sample\ size)}}$$

$$= \sqrt{\frac{(1.96)^2 \times 0.5(1-0.5)}{(10)}}$$

$$= 0.31\ or\ 31\%$$

Alternatively, by keeping the margin of error at 20%, and adjusting for a confidence level of 80%, the sample size comes out to be 10.

The small sample size could also be justified by the following:

- Pilots, trained on the same aircraft by the same airline, are trained according to the same airline training program and therefore they should react in a similar way in similar situations. Hence a small sample size should be representative of the whole group of pilots.
- All weather effects were turned off for the simulations which made the set-up scenarios largely ideal.
- Each airline does their own training and therefore pilots from other airlines would yield different results. And training in each aircraft is different, so one cannot compare E-190 with ERJ-145, for example.

To prove the above points, the data was further validated in section 6.1.

5.2. Method Followed

For this study, ten ERJ-145 certified airline pilots were recruited using convenience sampling methods. They each spent 3 hours in the Embraer Regional Jet (ERJ-145) Simulator (Figure 5-1) and were outfitted with SMI eye tracking glasses (Figure 2-4 & Appendix A). The collected data was processed using SMI BeGaze™ 3.6 software on a

standard laptop computer. The software licence and glasses were provided by the North West University School of Language.



Figure 5-1: Embraer ERJ-145 Simulator, showing calibration points. [44]

The study began with a calibration exercise. While wearing the glasses, each pilot was asked to look at three easily identifiable points within the cockpit that were scattered far away from each other but still within the pilot's field of view. For example; the analogue compass, the centre of their control column (or yoke) and the virtual horizon. The BeGaze™ Software would then inform the user whether the calibration was a success. Success was determined by concluding that the software was able to locate the calibration points in the video relative to where the pilot was looking. If it was successful then the recording of the session was commenced, if not, calibration was redone.

The instructor then loaded the simulator program and the pilots would fly according to the instructions given by the instructor. The ERJ-145 was not designed to land on unprepared runways, therefore all the runways within the simulator program were prepared runways. In order, to simulate an unprepared runway the instructor turned off

all the landing lights, markings and air traffic control before approach began. After flight, the recorded video was saved.

Areas of interest (AOIs) were identified as Primary Function Display (PFD), Outside (OUT), Navigational Display (ND), Centre Console (CC), Engine Indication and Crew Alerting System (EICAS) and Overhead Panel (OP). For further information on the instrument panels see Appendix B. The software then counted the number and duration of fixations, saccades and transitions within those various AOIs (See Figure 5-2). Note that the pilot's and co-pilot's field of view are mirrored with regards to instrument layout. However, the instruments themselves are not mirrored.

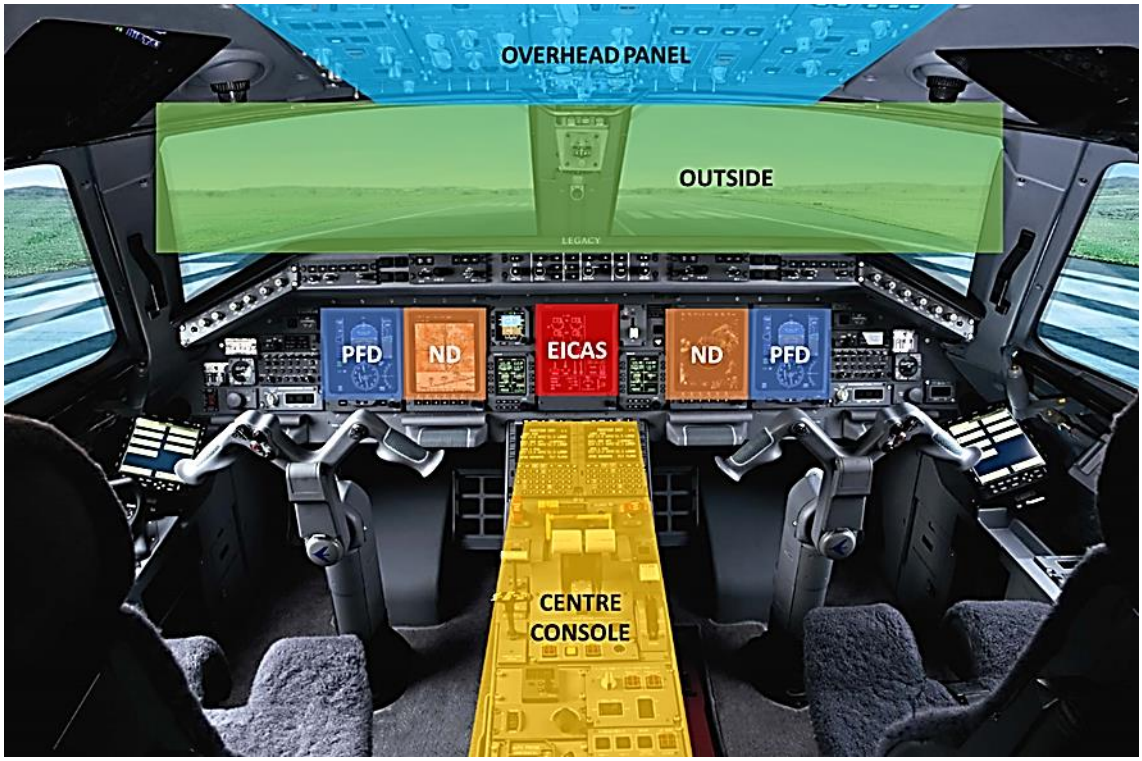


Figure 5-2: Allocated AOI's in ERJ-145 Simulator Cockpit. Picture [39]

The raw data was initially analysed using SMI BeGaze™, which automatically filtered the data while recording. The data extracted from the recordings was number of revisits, dwell time, visible time, entry time, fixation count and the transition matrix between AOIs. This data was extracted into a comma-separated (.csv) file that could then be

analysed using Microsoft Excel™ and GraphPad Prism™. The prepared runway data was validated by comparing pilots against each other as they did not all perform a prepared and unprepared landing approach. A test for outliers was also conducted using GraphPad Prism™. After validation and removal of outliers, the data for each AOI for the prepared and unprepared runway landings were then compared using statistical methods (two-way ANOVA, Tukey's multiple comparisons and unpaired t-tests).

5.3. Ethical considerations

Due to human involvement in the study, ethics clearance was necessary and was granted (MIAEC 008/18) for this investigation to take place. The participants were also given a participant information sheet (Appendix C – Participant Information Sheet) before the date of testing, and were asked to sign a letter of consent (Appendix D – Letter of Consent) before the experiment began.

5.4. Study details

The study was conducted over 4 days in an Embraer Regional Jet ERJ-145 simulator with 10 pilots from a local airline who have an average of 3500 flying hours between them. Each flying session was approximately 2 hours long and the pilots worked in pairs as captain and first officer. Each took turns wearing the eye tracking glasses while they were flying.

Each of the pilots had to answer a questionnaire on their flying experience and the results of this are shown in Figure 5-3. The left bar shows each pilot's total number of flying hours, the middle bar shows their total flying hours in the ERJ-145 and the right bar shows how many of those hours are ERJ-145 simulator hours. The pilots were paired as follows; A&B, C&D, E&F, G&H and I&J, where the first letter represents the captain and the second letter, the first officer.

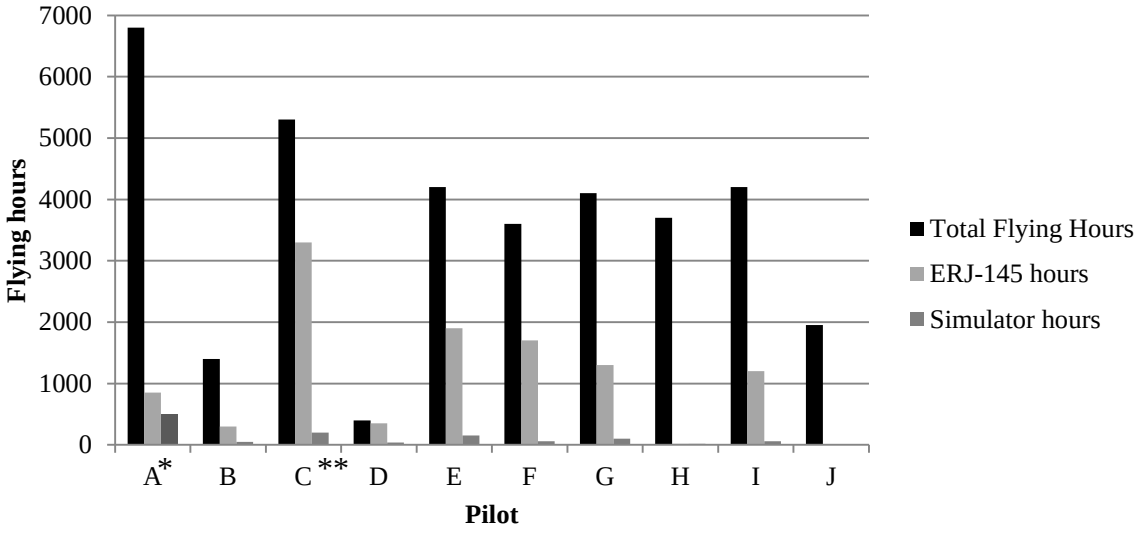


Figure 5-3: Pilot experience shown in total number of flying hours, number of flying hours in the ERJ-145 and number of flying hours in the ERJ-145 simulator. *Pilot with the most number of hours. **Most experienced pilot in the ERJ-145.

A total of 24 approaches and landings were performed, of which 17 were prepared runway landings and 7 were unprepared runway landings. The number of landings that were performed by each pilot are shown in Figure 5-4.

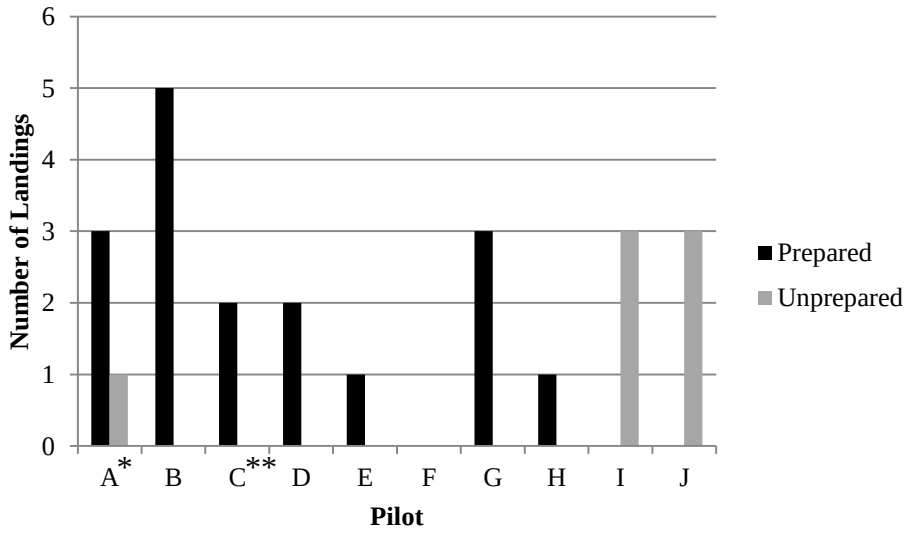


Figure 5-4: Number of prepared and unprepared runway landings performed by each pilot. *Pilot with the most number of hours. **Most experienced pilot in the ERJ-145.

Due to the scenarios given to them by the instructor, not every pilot could complete both a prepared and unprepared landing, and some pilots (Pilot F for example) did not complete a landing at all, this pilot was therefore excluded from the study. Pilot A was the only pilot that completed both a prepared and unprepared runway landing. Pilot B completed the most number of landings, this was due to the test scenarios he/she was faced with.

5.5. Examples of Video Data

The data was extracted from the videos taken during the study. These are the videos that were captured from the eye tracking glasses through the BeGaze™ software. Screenshots from the videos are shown below. Each screenshot shows fixations and saccades within a 2 second period. The circles on the figures show fixations and the lines show saccades. The size of the circle represents the duration of the fixation; i.e. the larger the circle, the longer the fixation. The darker circle represents the point that the pilot is currently looking at. Figure 5-5 and Figure 5-6 were taken during a prepared runway approach and Figure 5-7 and Figure 5-8 were taken during an unprepared runway approach. As can be seen from Figure 5-6, the prepared runway is lit up and easy to see whereas the unprepared runway (Figure 5-8) is indistinguishable from the terrain.



Figure 5-5: Screenshot of visual pattern of pilot during approach on prepared runway. Here the pilot is fixating between the airspeed (PFD), virtual horizon (PFD) and compass heading (ND).



Figure 5-6: Screenshot of visual pattern of pilot during approach on prepared runway, showing runway. Here the pilot is shown fixating between the virtual horizon (PFD), the altitude (PFD) and the runway outside (OUT).

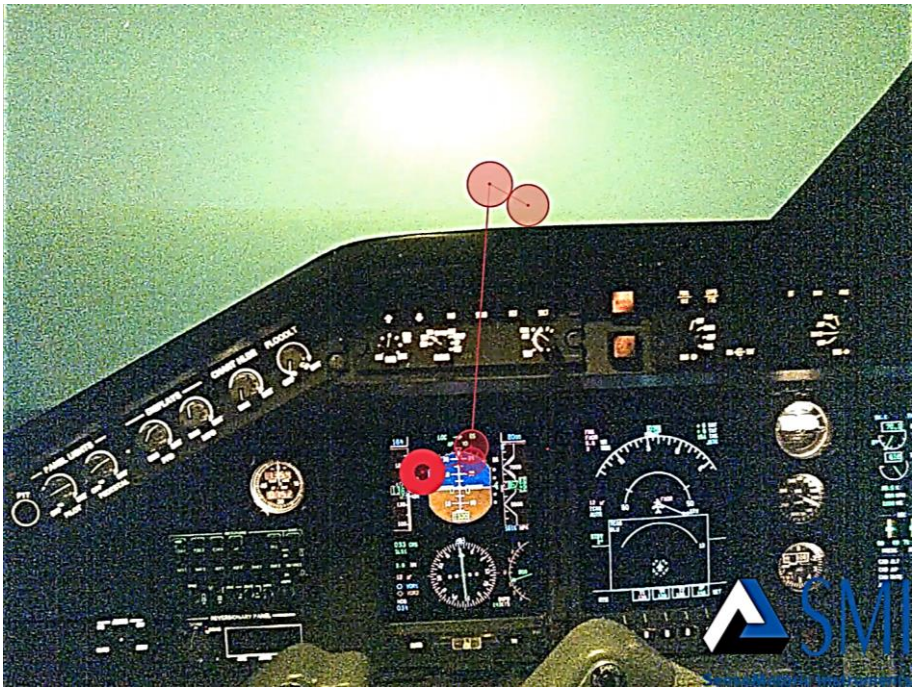


Figure 5-7: Screenshot of visual pattern of pilot during approach on unprepared runway. Here the pilot is shown fixating between the airspeed (PFD), virtual horizon (PFD) and outside the windscreen (OUT).

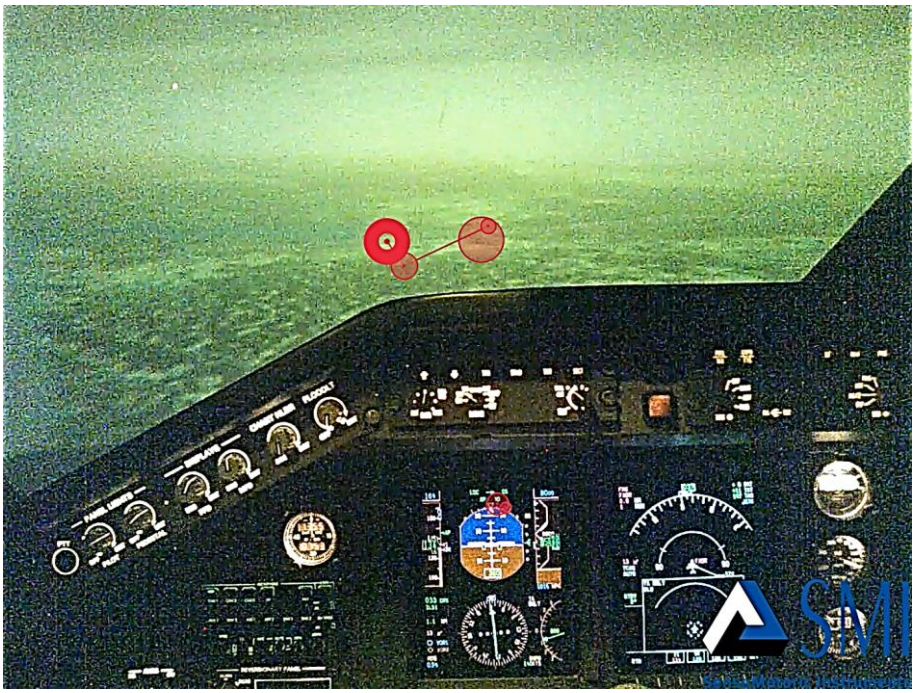


Figure 5-8: Screenshot of visual pattern of pilot during approach on unprepared runway, showing runway. Here the pilot is shown fixating on the runway outside (OUT), with smaller fixations on the virtual horizon (PFD) to make sure the aircraft attitude is correct.

6 RESULTS

The mean dwell time, percentage dwell time, fixation count and fixation rate were extracted from the data for each pilot and each AOI.

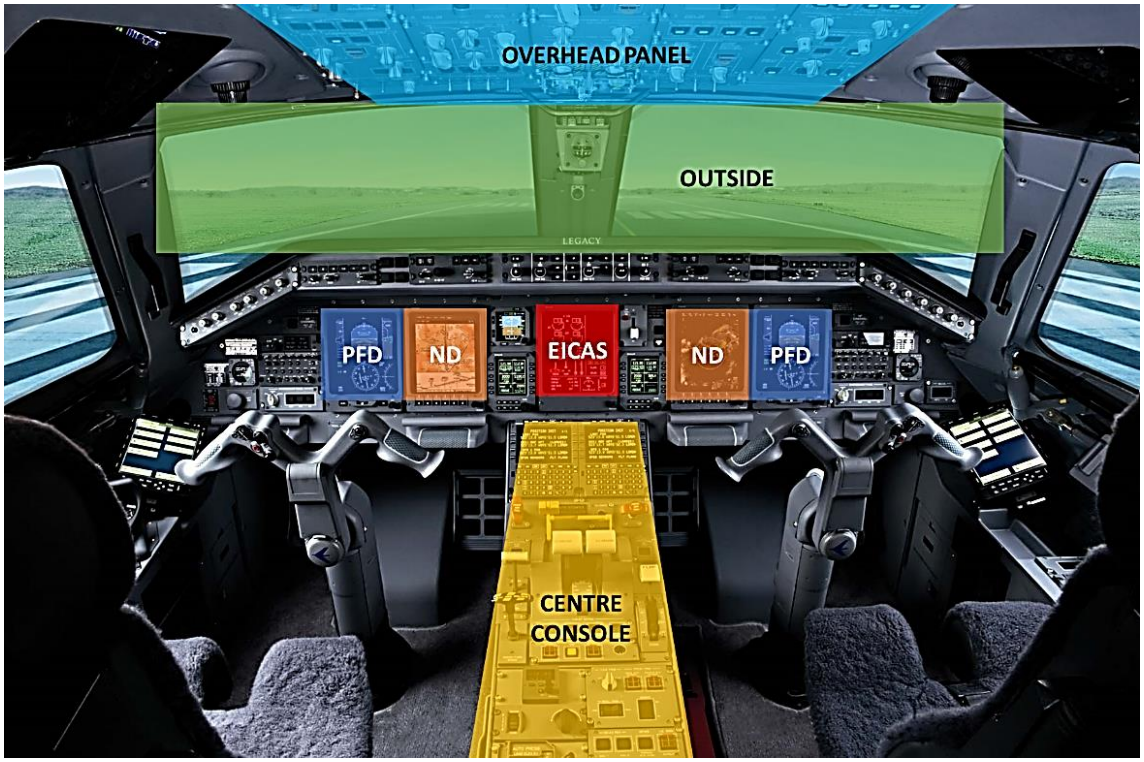


Figure 5-2 has been repeated below so that the reader doesn't have to keep paging back to see the allocation of the AOIs

6.1. Validation of Data

Considering that all the pilots did not perform both a prepared and unprepared runway landing (Figure 5-4), the data between each pilot had to be validated against each other. To achieve this, a Tukey's multiple comparison test was conducted.

Out of the 9 pilots who performed at least one approach and landing (Pilot F was excluded from the results as he/she did not perform a landing during the trial), only pilot A performed both a prepared and unprepared runway landing. Each landing was labelled according to the pilot (i.e. A, B, C, etc) and their landing number. For example, pilot A performed four landings and therefore each landing was labelled A1, A2, A3 and A4. All the landings were then split into prepared and unprepared runway types and

were compared against each other for each of the six AOI's dwell time, percentage dwell time, fixation count and fixation rate.

During validation, it was found that pilot H was an outlier, this was explained as he/she wore glasses and therefore the glasses tended to interfere with the results of the eye-tracking glasses, especially during the dwell time. Therefore, pilot H was removed from the study.

After removing the outlier, the validation was conducted again and showed no significance between pilots, which suggests that the pilots tend to fixate and dwell on AOIs in a similar way to each other. The complete results of this validation can be found in Appendix E.

6.2. Mean Dwell Time per AOI visit

The mean dwell time refers to the average time a pilot spends reading/processing data from an AOI. That is, the mean dwell time per AOI visit would refer to the average time a pilot spends reading/processing data from an AOI each time he/she visits that AOI.

By averaging the mean dwell time of the pilots for each AOI and dividing it by the number of visits to that AOI, the mean dwell time per AOI visit was determined (Figure 6-1). These values were split into prepared and unprepared runway landings and were then statistically analysed using an ordinary two-way ANOVA and Bonferroni's multiple comparison test. The two-way ANOVA returned a significance between the AOI's ($P<0.0001$) but no significance between prepared and unprepared runway landings. It is observed that the mean dwell time decreases on all AOIs when landing on an unprepared runway except for the OUT AOI which increases.

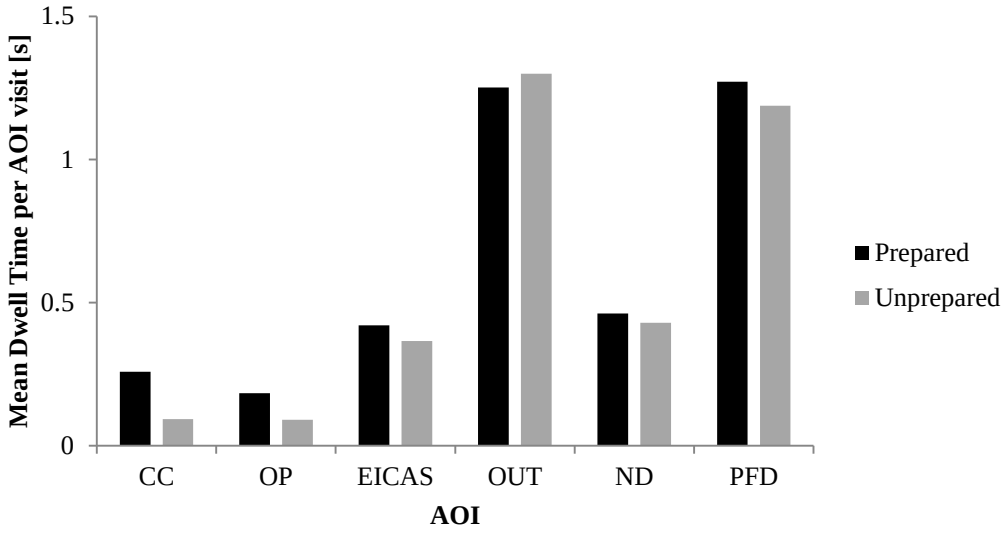


Figure 6-1: Mean dwell times for prepared and unprepared runway landings per AOI

For clarification on number of revisits; Figure 6-2 shows the mean number of revisits per AOI for prepared and unprepared runway landings. In this case, the only two AOIs that reported increases in revisits were OUT and PFD.

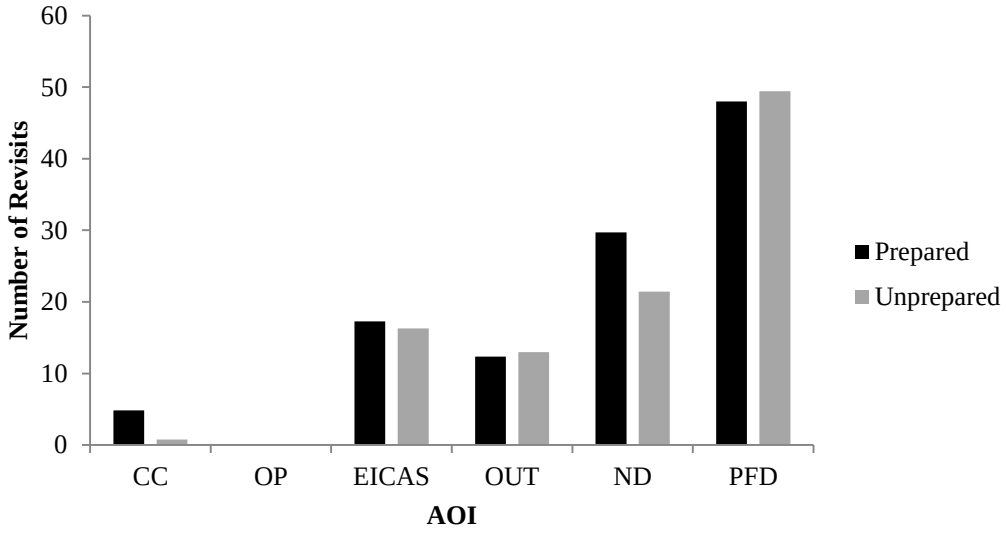


Figure 6-2: Number of revisits per AOI for prepared and unprepared runway landings.

To investigate further which AOI's were significant to each other, the Bonferroni's multiple comparison test (alpha = 5%) was conducted and the significant results are shown in Table 6-1.

Table 6-1: Mean Dwell Time per AOI visit Bonferroni's multiple comparison data. Only showing significant comparisons.

	AOI Comparison	Mean Diff.	Significance	P-Value
Prepared Runway	OUT vs. CC	0.9931	Extremely Significant	0.0001<P<0.001
	PFD vs. CC	1.013	Extremely Significant	0.0001<P<0.001
	OUT vs. OP	1.068	Extremely Significant	0.0001<P<0.001
	PFD vs. OP	1.088	Extremely Significant	0.0001<P<0.001
	OUT vs. EICAS	0.8315	Very Significant	0.001<P<0.01
	PFD vs. EICAS	0.8512	Very Significant	0.001<P<0.01
	ND vs. OUT	-0.7894	Very Significant	0.001<P<0.01
	PFD vs. ND	0.8091	Very Significant	0.001<P<0.01
Unprepared Runway	OUT vs. CC	1.206	Extremely Significant	0.0001<P<0.001
	PFD vs. CC	1.094	Extremely Significant	0.0001<P<0.001
	OUT vs. OP	1.209	Extremely Significant	0.0001<P<0.001
	PFD vs. OP	1.097	Extremely Significant	0.0001<P<0.001
	OUT vs. EICAS	0.9314	Very Significant	0.001<P<0.01
	PFD vs. EICAS	0.8199	Very Significant	0.001<P<0.01
	ND vs. OUT	-0.8696	Very Significant	0.001<P<0.01
	PFD vs. ND	0.7582	Very Significant	0.001<P<0.01

6.3. Percentage Dwell Time

The percentage dwell time refers to the mean AOI dwell time divided by the total dwell time over all AOIs. This indicated how much of the pilots' dwell time is spent on each AOI (Figure 6-3). The values were, again, split between prepared and unprepared runway landings and the AOI's were statistically analysed using a two-way ANOVA and Bonferroni's multiple comparison test. The two-way ANOVA returned a significance between the AOI's ($P<0.0001$) but no significance between prepared and unprepared runway landings; similarly, to the mean dwell time per AOI visit data. The trend here shows all the AOI's percentage dwell times decreasing for unprepared runway landings except the PFD which increased by 8%.

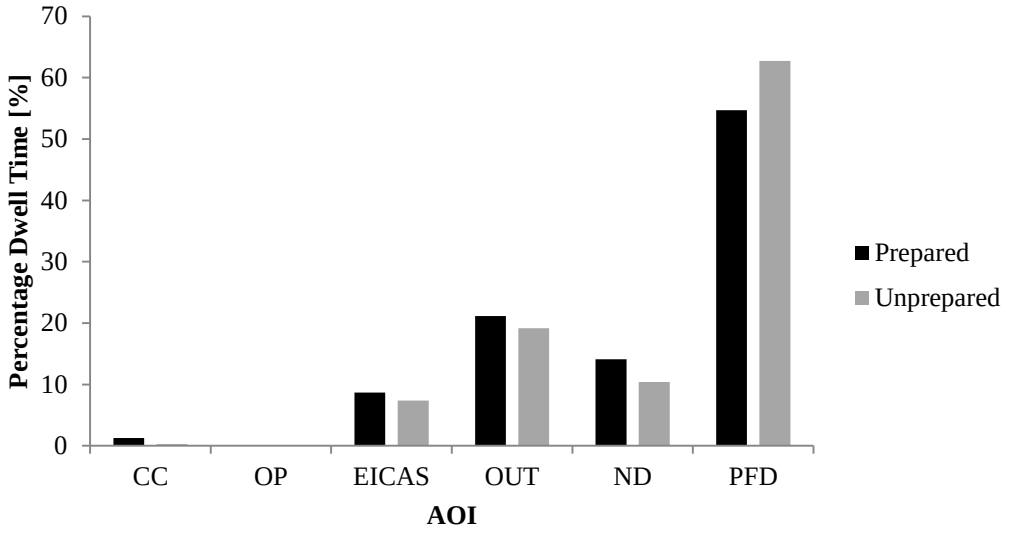


Figure 6-3: Percentage dwell times per AOI for prepared and unprepared runway landings

To investigate further which AOI's were significant to each other, the Bonferroni's multiple comparison test (alpha = 5%) was conducted and the significant results are shown in Table 6-2.

Table 6-2: Percentage dwell time Bonferroni's multiple comparison data. Only showing significant comparisons.

	AOI Comparison	Mean Diff.	Significance	P-Value
Prepared Runway	PFD vs. CC	53.42	Very Significant	0.001<P<0.01
	PFD vs. OP	54.54	Very Significant	0.001<P<0.01
	PFD vs. EICAS	45.99	Very Significant	0.001<P<0.01
	PFD vs. OUT	33.52	Significant	0.01<P<0.05
	PFD vs. ND	40.59	Very Significant	0.001<P<0.01
Unprepared Runway	PFD vs. CC	62.46	Extremely Significant	0.0001<P<0.001
	PFD vs. OP	62.63	Extremely Significant	0.0001<P<0.001
	PFD vs. EICAS	55.35	Very Significant	0.001<P<0.01
	PFD vs. OUT	43.59	Significant	0.01<P<0.05
	PFD vs. ND	52.33	Very Significant	0.001<P<0.01

6.4. Fixation Count

The fixation count is the number of times a pilot fixates on an AOI. These values were averaged for each AOI and compared between prepared and unprepared runway type landings. Statistical analysis of this data was done using an ordinary two-way ANOVA and Bonferroni's multiple comparison test. The two-way ANOVA returned a significance between the AOI's ($0.0001<P<0.001$) but no significance between prepared and unprepared runway landings. There was an increase of 60 fixations for the unprepared runway PFD fixation count compared to the prepared runway PFD fixation count; this is clearly the most important instrument panel for flight. The only other AOI to increase was the OUT AOI.

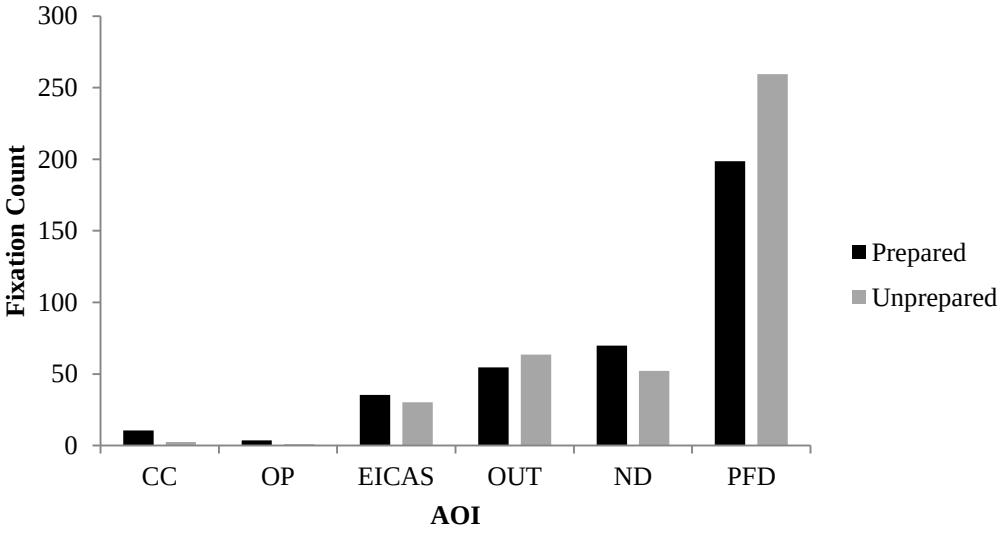


Figure 6-4: Fixation Count per AOI for prepared and unprepared runway landings.

To investigate further which AOI's were significant to each other, the Bonferroni's multiple comparison test (alpha = 5%) was conducted and the significant results are shown in Table 6-3.

Table 6-3: Fixation count Bonferroni's multiple comparison data. Only showing significant comparisons.

	AOI Comparison	Mean Diff.	Significance	P-Value
P-R	PFD vs. CC	53.42	Significant	0.01<P<0.05
	PFD vs. OP	54.54	Significant	0.01<P<0.05
Unprepared Runway	PFD vs. CC	62.46	Very Significant	0.001<P<0.01
	PFD vs. OP	62.63	Very Significant	0.001<P<0.01
	PFD vs. EICAS	55.35	Significant	0.01<P<0.05
	PFD vs. OUT	43.59	Significant	0.01<P<0.05
	PFD vs. ND	52.33	Significant	0.01<P<0.05

6.5. Fixation Rate

The fixation rate refers to the number of fixations that the pilot performs on each AOI per second. The fixation rate can be thought of as the rate (fixations/second) that the pilots need to read or process data from an AOI. The fixation rate was calculated by fixation count of each AOI divided by the total fixation time for each AOI, this data is represented in Figure 6-5. Statistical analysis of this data was done using an ordinary two-way ANOVA and Bonferroni's multiple comparison test. The two-way ANOVA returned a significance between the AOIs (0.001<P<0.01) and a significance between prepared and unprepared runway landings (0.01<P<0.05). It was observed that the clear trend was an increase in fixation rate between prepared and unprepared runway landings.

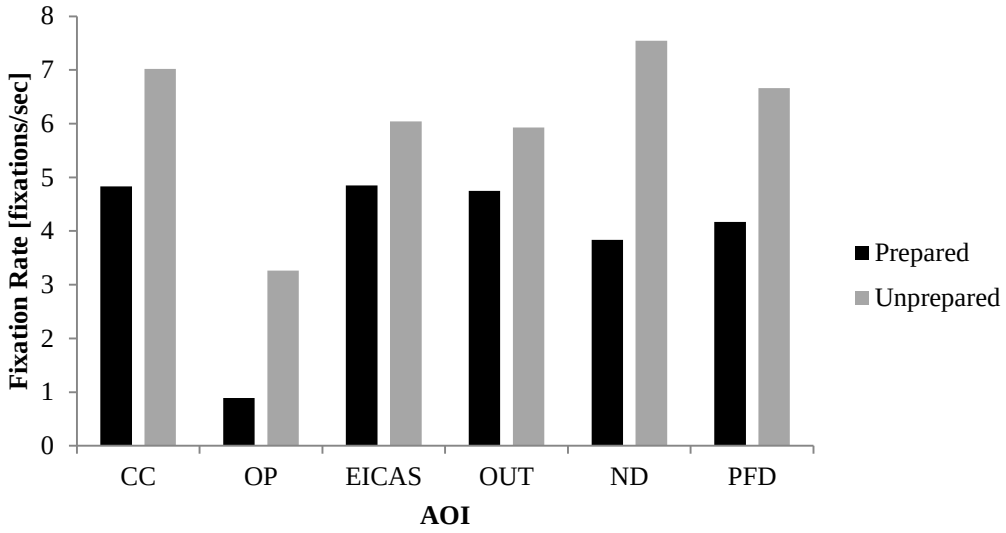


Figure 6-5: Fixation rate per AOI for prepared and unprepared runway landings.

To investigate further which AOI's were significant to each other, the Bonferroni's multiple comparison test (alpha = 5%) was conducted and it was found that there was no significance between any of the individual AOIs as there was for the other parameters.

Fixation rate was the first parameter that returned a significant difference between prepared and unprepared runway landings. To clarify this significance an unpaired t test was done to check the mean differences between prepared and unprepared runway AOIs. The t test returned significance between unprepared and prepared runway landings (P=0.0312), confirming the two-way ANOVA results.

6.6. AOI Transition Matrix

To understand the order that the pilot transitions between AOIs, a transition matrix for each landing was extracted in SMI BeGaze™ and averaged for all prepared and unprepared runway sessions (Table 6-4 and Table 6-5). The matrices have been colour coded to show the higher numbers in darker fill colours and the lower numbers in lighter fill colours. This allows us to verify which AOIs are most transitioned between during prepared and unprepared runway approaches and landings, (Figure 5-2 has been repeated below so that the reader doesn't have to keep paging back to see the allocation of the AOIs).

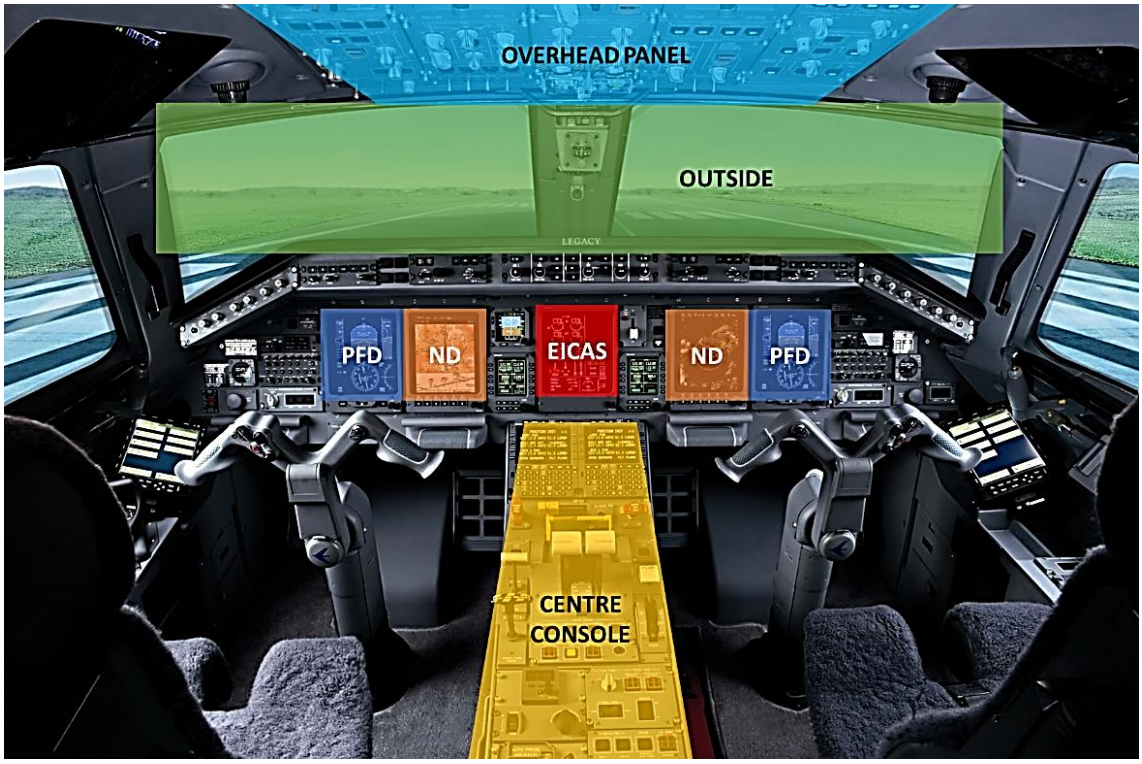


Table 6-4: Prepared Runway AOI Transition Matrix. The table is read as follows: Number of transitions from [Row Title] to [Column Title], e.g.: the number of transitions from ND to PFD was 8.13.

From ↓\ to →	CC	OP	EICAS	OUT	ND	PFD
CC	0.00	0.00	0.19	0.63	0.25	0.56
OP	0.00	0.00	0.00	0.00	0.06	0.06
EICAS	0.19	0.00	0.00	0.50	0.94	4.13
OUT	0.63	0.06	0.88	0.00	0.19	3.06
ND	0.50	0.00	1.25	0.25	0.00	8.13
PFD	0.50	0.00	2.63	4.00	9.06	0.00

Table 6-5: Unprepared Runway AOI Transition Matrix. The table is read as follows: Number of transitions from [Row Title] to [Column Title], e.g.: the number of transitions from ND to PFD was 10.57.

From ↓\ to →	CC	OP	EICAS	OUT	ND	PFD
CC	0.00	0.00	0.00	0.00	0.57	0.00
OP	0.00	0.00	0.14	0.00	0.00	0.29
EICAS	0.00	0.14	0.00	0.86	0.57	3.43
OUT	0.29	0.14	0.71	0.00	2.29	9.29
ND	0.00	0.00	0.14	4.14	0.00	10.57
PFD	0.29	0.00	4.29	6.86	11.86	0.00

6.7. Further Observations

During the study the following were also observed and could be used as the basis for further studies:

- When the pilots spoke to each other, they tended to look at each other's lips, rather than at their eyes. This shows that the pilots are lip-reading as well as listening so that they can take in as much information in a short period of time. When this was pointed out to them they didn't even know they were doing it, so it appears it is inherent from their training.
- During emergency situations, when the alarm lights were activated, the more experienced pilots did not look at the flashing lights, but rather registered the sound of the alarm and almost instantly whet into emergency mode. Whereas, the less experienced pilots tended to be distracted by the light first and then only registered that there was an emergency.

7 DISCUSSION

The discussion will explore the differences and similarities between the prepared and unprepared runway landings by looking at instrument importance, mean dwell time per AOI visit, percentage dwell time, fixation count and fixation rate.

7.1. Limitations

The possible limitations to this study were:

1. Reduced peripheral vision due to older version of glasses being used.
2. Any conditions that would block or hinder the direct line between the camera and the eye's pupil, such as wearing glasses, sunglasses, having drooped eyes or wearing lots of dark make-up, may result in less accurate readings.
3. Limited number of participants due to specialisation of study and amount of time given in simulator.
4. Due to the cost of using the simulator, the researcher had to fit in with the instructors testing schedule, rather than designing a common experiment for each of the pilots to fly. Therefore, the only sections of the testing programs that were analysed were the approach and landing of all sessions. This also meant that the researcher had to sit in on the full session and may only have been able to record one landing throughout the day, depending on the testing schedule being done. Furthermore, not all the pilots were able to complete both a prepared and unprepared runway landing, due to this schedule.

7.2. AOI order of importance

The order of importance of AOI's for approach and landing were classified as follows, where 1 is the most crucial and 6 the least crucial for general approaches and landings:

1. Primary Function Display (PFD)
2. Outside (OUT)
3. Navigational Display (ND)
4. Engine Indication and Crew Alerting System (EICAS)

5. Centre Console (CC)
6. Overhead Panel (OP)

The OP and CC AOIs are not crucial instruments during approach and landing and they have no bearing on the study but were included to represent a full picture of the study. These two instruments are more vital during emergency procedures and during logging of flight data. The EICAS and ND are necessary for landing but not as crucial as OUT and PFD. The EICAS will usually only be looked at in case of engine problems otherwise it is just scanned over to check that the engines are working properly. The ND is usually set up from the CC and shows the navigational data for the flight. This is generally looked at to determine at what heading the runway is and how far away it is. Once the pilot knows the navigational data they use their PFD to determine their altitude and speed approaching the runway and pilots generally check outside the windscreen to confirm their position with regards to the PFD. This was shown to be true in all cases in this study.

7.3. Mean Dwell Time per AOI visit

All significant comparisons were between the OUT and the PFD AOIs. However, there was no significance between the two of them, which can also be seen from Figure 6-1, as their values are very similar (Δ 0.02s) and more time is spent on them than the rest of the AOIs. These two AOI's are crucial for landing as the pilots need to continuously be checking their altitude and speed (PFD) in comparison to where the aircraft is to the runway (OUT) when coming in to land. The mean dwell time in these AOIs is longer than the other four AOIs as the pilots need more time to read/process data from these two areas of interest.

The insignificance between the OUT and PFD AOI's shows that they are both equally favoured during all landings. However, the mean dwell time for unprepared runway landings on the OUT AOI was higher than the prepared, and was lower than prepared for the PFD AOI. This suggests that, during unprepared landings the pilots' mean dwell time is focused more outside than inside the cockpit; there is no significance in the results to support this observation, but this may be due to the small sample size.

7.4. Percentage Dwell time

All significant comparisons were found between the PFD and all other AOIs. This is easily seen on the graph (Figure 6-3) as the PFD values are a lot higher than the rest of the AOIs (55% for prepared runway landings and 63% for unprepared runway landings). This data shows that most of the dwell time is spent on the PFD regardless of runway type.

Unlike the data in the mean dwell time per AOI visit, a significant difference between the OUT AOI and the PFD was found. This is due to the PFD percentage dwell time being higher than the OUT AOI (Δ33% for prepared and Δ43% for unprepared), suggesting that pilots use the PFD more than any other instrument in the cockpit during approach and landing, regardless of runway type.

When looking at the difference between percentage dwell time for prepared and unprepared runway types, there is minimal difference between the two. The order of importance stays the same and there is no significant difference between the two runway types.

However, a noticeable trend in the AOIs is that the only AOI that increases when going from a prepared to unprepared runway landing is the PFD. All the other AOIs' percentage dwell times decrease. This may suggest that during an unfamiliar, or less likely situation the pilot will spend more time dwelling on the PFD to ensure they are correct in their landing parameters.

7.5. Fixation Count

Significance was found between the PFD and the CC and OP for prepared runway landings, and between PFD and all other AOIs for unprepared runway landings. This correlates with the percentage dwell time, in that it shows that the PFD is the most viewed AOI than any other during approach and landing, regardless of runway type. However more fixations were counted during unprepared runway landings for PFD (Δ60.7 fixations) and OUT (Δ9.0 fixations), whereas all the other AOIs decreased the number of fixations for unprepared runway landings. Again, there was no significance found between the prepared and unprepared runway fixation counts.

A similar conclusion can be drawn for fixation count as was for percentage dwell time: the more unfamiliar the situation, the more often the pilot needs to check his crucial instruments.

7.6. Fixation Rate

Outcomes from the fixation rate returned significance between the averages of the AOIs and not between the individual AOIs as there were for the other parameters. The insignificance between the AOIs demonstrates that a pilot will not need more time to read/process data depending on the AOI, but rather that it takes him/her the same number of fixations per second to read an instrument regardless of the instrument.

Fixation rate was the first parameter that returned a significant difference between prepared and unprepared runway landings. By looking at Figure 6-5, the unprepared runway values are higher in all AOI cases, this demonstrates that the pilot takes longer to process the information from an AOI when placed in an unfamiliar (less common) situation.

7.7. AOI Transition Matrix

To make recommendations on instrument layout within the cockpit, one would need to know the order in which a pilot looks at his/her instruments. By knowing these transitions between AOIs the reading pattern can be understood.

The number of transitions were highest between the PFD and the ND for both prepared and unprepared runway landings whereas, the transitions between the PFD and OUT were significantly higher for unprepared compared to prepared runway landings.

The PFD is important while flying as it’s the main instrument that gives information about speed and altitude and therefore it is reasonable to understand that this would be a reference point for transitions. In both prepared and unprepared approaches, pilots require navigation and thus refer to the ND AOI regularly while coming in to land. This explains why the PFD and ND transitions are so high.

In the case for the unprepared runway landing the transition between the PFD and OUT were higher because the pilot needs to look outside the windscreen when coming in to land on unprepared runways more often than for prepared runway approaches.

This seems to correlate well with the critical research question and would lead to the recommendation that there should be a Head-Up Display (HUD) installed for aircraft designed to land on both prepared and unprepared runways. The HUD would reduce the number of transitions needed to get between the PFD and the OUT AOIs, as the PFD would be displayed over the windscreen and therefore the pilot would only need to adjust the focus of his/her eyes rather than moving their focus to another location.

7.8. General Discussion

Overall, pilots have similar visual patterns while landing on all runway types. Their main area of focus is on PFD and OUT AOIs as these are crucial for approaches. This compares well to Anders' study [15], where he showed that pilots favour their PFD instruments more often than the other panels during approach and landing. From this study it is also suggested that there is a trend for preferences of different AOIs between prepared and unprepared landings.

The fixation rate and the transition matrix returned a significant difference between the prepared and unprepared approaches. These proved that the pilot transitioned between the windscreen and the instrument panel more during unprepared runway landings. This lead to the recommendation of a Heads-Up Display being installed in the cockpit to reduce eye movements and hence pilot fatigue. The other parameters did not show a difference between prepared and unprepared approaches.

8 CONCLUSIONS

The study showed the importance of each AOI during all approaches. It also proved that there is a difference in visual patterns between prepared and unprepared runway approaches. It is suggested that further studies are done to analyse the trend difference within the two types of landings.

The fixation rate showed that the pilot is inclined to focus outside (OUT) more during unprepared runway approaches. The transition matrix revealed that the pilot transitioned between the Primary Function Display (PFD) and the windscreen (OUT) more during unprepared runway landings compared to prepared runway landings. This suggests that the cockpit layout could be modified to suit landing types.

9 RECOMMENDATIONS

9.1. Heads-Up Display (HUD)

For unprepared runway landings, the pilot tended to increase fixation count and mean dwell time when looking outside. The transition matrices also showed an increase in transitions to and from the windscreen. This leads the author to recommend that aircraft that are designed for both prepared and unprepared runway landings should install a HUD within the cockpit to reduce pilot workload and increase situational awareness.

9.2. Pilot and Instructor Training

The author recommends that eye tracking be used in pilot and instructor training. The reaction from the instructors that sat in the simulator sessions, showed that the eye tracking technology could be very useful during pilot training. The modern eye tracking devices are non-invasive and can track both eye and head movements while a pilot is performing their daily tasks by minimally hindering or distracting them. During training the instructors can view the pilot's eye movements and understand where the pilot is looking during different training tasks. This allows the instructor to determine the pilot's cognitive state and decision-making processes throughout the training. Also, the sessions can be recorded, and the pilot can use the data to better understand what he/she did in a certain situation and how they could adjust their scanning patterns to make better and faster decisions. Instructor training could also benefit from this technology as the instructors could be taught to identify certain visual patterns and ensure their pilots learn these during training especially in emergency situations, the visual patterns could assist in saving time to make faster decisions.

9.3. Further Studies

For further studies a larger sample size could be used, and the pilots should each do both prepared and unprepared runway landings, this will give more accurate results and help to validate this study. Furthermore, an experiment can be designed so that each pilot can fly the same scenario then the results are also more comparable.

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A. APPENDIX A – SMI® EYE TRACKING GLASSES SPECIFICATIONS [45]

System Type: Video based glasses-type eye tracker

Sampling Rate: 30Hz binocular

Method: Dark pupil, pupil-cr

Binocular Tracking: Yes (auto parallax correct)

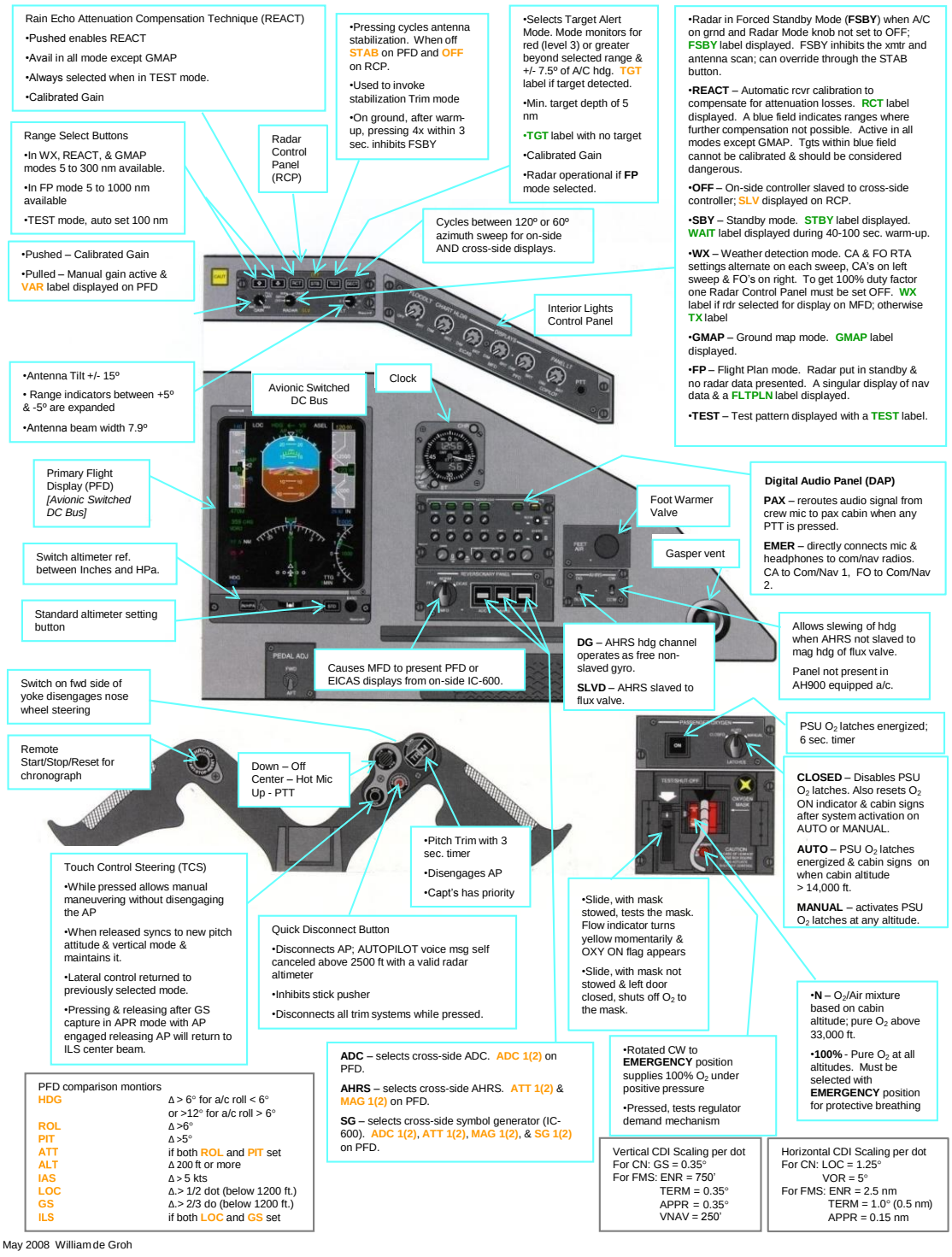
Accuracy: 0.5 degrees over all distances

Gaze tracking range: 80° horizontal, 60° vertical

Additional Details: HD Scene Camera Resolution: 1280x960

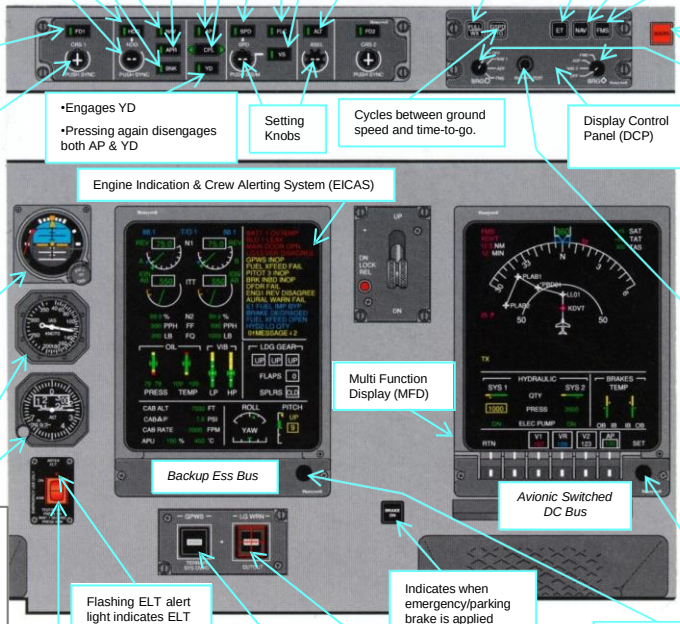
B. APPENDIX B – EMBRAER E145 COCKPIT PANELS [46]

EMBRAER 145 RIGHT MAIN INSTRUMENT & GLARESHIELD PANELS



May 2008 William de Groh

EMBRAER 145 CENTER MAIN INSTRUMENT & GLARESHIELD PANELS



•Bank angle reduced from 27º to 14º in HDG mode .

•Auto selected climbing > 25,000 ft & canceled < 24,750 ft in HDG mode.

•Annunciated only in HDG Select mode

Couples FD to nav source selected on flying pilot's DCP. VOR/LOC if **NAV** selected and LNAV if **FMS** selected

•Engages AP & YD

•Pressed again disengages AP but keeps YD

•Cycles between full rose HSI & sector format on PFD

•In sector format WX radar can be displayed

•First press enters Elapsed Timer Mode

•Start/Stop/Reset

Same as NAV but with higher gain. Also enable GS Mode.

Allows CA's or FO's FD to control the AP

•Hdg Hold (**ROL**) holds present hdg when selected

•Hdg Select (**HDG**) follows hdg bug

•Speed Hold Mode

•Flight Level Change

Cycles between on-side VOR/LOC SRN source (green) or cross-side VOR/LOC SRN source (yellow)

•Vertical Speed Hold Mode

•Altitude Hold Mode

Cycles between on-side FMS LRN source (magenta) and cross-side FMS LRN source (yellow)

•Allows hdg selection

•Pressing synchronizes hdg bug to current hdg

Displays FD bars

Master Warning Button

•Allows crs selection

•Pressing synchronizes selected course to VOR bearing

•Engages YD

•Pressing again disengages both AP & YD

Setting Knobs

Cycles between ground speed and time-to-go.

Display Control Panel (DCP)

OFF – Associated bearing pointer sources disabled

NAV– Selects associated VOR as bearing pointer source

ADF – Selects associated ADF as bearing pointer source

FMS – Selects associated FMS as bearing pointer source

Engine Indication & Crew Alerting System (EICAS)

Standby Attitude Indicator

•Pull to cage & rotate to adjust miniature airplane

•Power warning flag

- ➢Power off
- ➢Caged
- ➢Open motor winding
- ➢Loss of power

•Essential DC Bus 2

•Rotation allows setting Radio Altimeter decision height

•On grnd, pressing activates IC-600 first level IBIT test. If held > 6 sec. activates IC-600 second level IBIT test. EICAS test commanded from CA's panel only.

•In flight, pressing activates Radio Altimeter Test

- ➢**TEST** displayed
- ➢100 +/- 10 ft

Multi Function Display (MFD)

Standby Airspeed Indicator

Standby Altimeter

Backup Ess Bus

Avionic Switched DC Bus

Optional Integrated Standby Instrument System (ISIS)

•Replaces the three electromechanical standby instruments with a single LCD screen

•Powered from Essential Bus 2

•**CAGE** button resets attitude only

•**STD** button sets standard barometer setting

•The **+** or **–** keys adjust brightness

•Rotary knob allows altimeter setting

Flashing ELT alert light indicates ELT transmitting

Indicates when emergency/parking brake is applied

Rotation allows setting airspeed bug values

Rotation allows pilot to scroll through EICAS messages if display limit of 15 exceeded.

•Inhibits EGPWS when approaching airports not covered by EGPWS database thus avoiding unwanted terrain alerts.

•Striped bar in button when pressed

•Cancels LANDING GEAR voice msg. in case of Radio Altimeter loss only when flaps < 22º

•Striped bar in button when pressed

•Striped bar extinguishes if TLs advanced or flaps set above 22º , or gear down & locked

•Flight Level Change Mode

•Climb

- ➢240 kts / 0 to 10,000 ft
- ➢240 kts to 270 kts / 10,000 to 12,000 ft
- ➢270 kts / 12,000 to 17,377 ft
- ➢0.56M / 17,377 to 37,000 ft

•Descend

- ➢-2,000 fpm / 37,000 to 12,000 ft
- ➢-2,000 to -1,000 fpm / 12,000 to 10,000 ft
- ➢-1,000 fpm / less than 10,000 ft

•**ON** – Activates ELT

•**ARM** – Allows automatic activation

•TEST/RESET function enabled by pressing **ON**, waiting 1 sec. then pressing **ARM**

•RESET function deactivates ELT after manual or auto activation

FMS Roll Cmds for "Direct To" changes

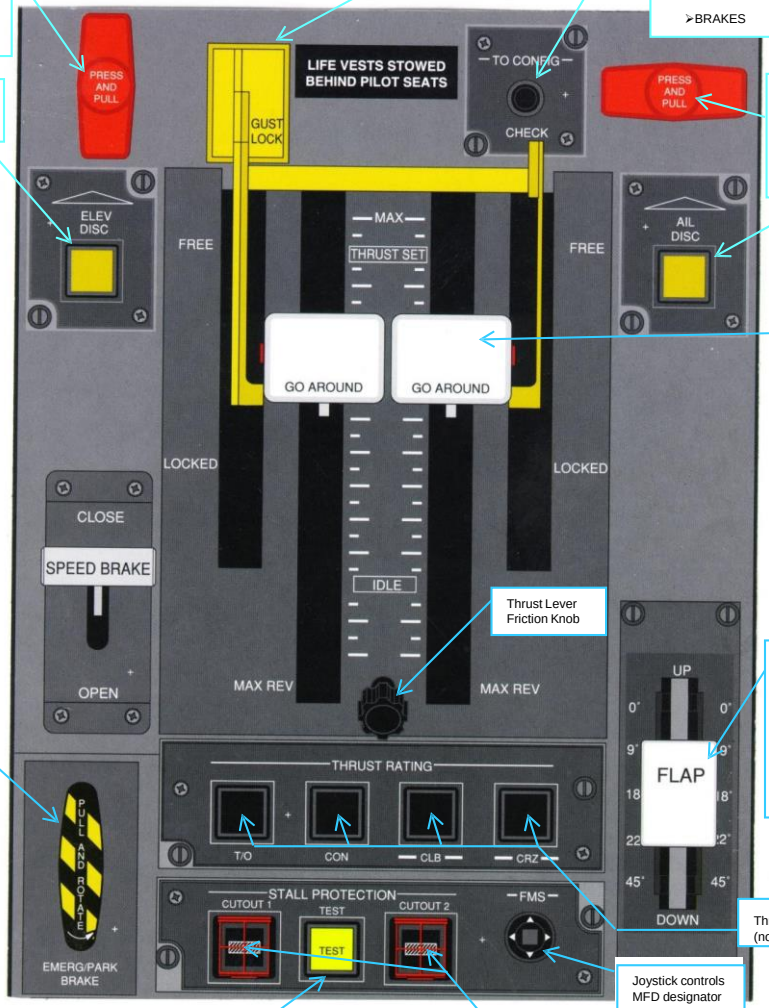
•30 bank up to 20K

•Dec. linearly above 20K up to 32K

•20 bank above 32K

•Roll rate limited to 3/sec

EMBRAER 145 CENTER PEDESTAL



Inhibition Logic
- Takeoff
  - Active > V_1-15
  - Deactive. RA > 400 ft, or < 60 kts, or > 1 min.
- Landing
  - Valid < 200 ft
  - Deactve. WOW > 3 sec., or > 1 min.

- Mechanical gust lock secures only the elevator
- Electromechanical gust lock does the same thing but uses a solenoid and locking pins installed in the horizontal stabilizer. Powered by DC Bus 2 & incorporates an amber indication light on the glareshield.

- Checks takeoff configuration warning by simulating TLs advanced
- If ok, "TAKEOFF OK" voice message
- If fail, "TAKEOFF " voice message & **NO TAKEOFF CONFIG** EICAS msg
  - ➢FLAPS
  - ➢SPOILERS
  - ➢TRIM
  - ➢BRAKES

- Disconnects CA's elevator control from FO's
- CA's side has all AP servos & stick pusher
- Cannot be reset in flight

Illuminates when disconnection mechanism activated

- Disconnects CA's aileron control from FO's
- FO's side has roll trim actuator & artificial feel unit
- Cannot be reset in flight

Illuminates when disconnection mechanism activated

Thrust Reversers have 3 locking systems. The Primary & Secondary are electrically controlled & hydraulically actuated. The third lock is completely electric. Loss of electric power latches locks closed

MAX – max. takeoff rating mode at any time

THRUST SET – FADEC controls engine to achieve N_1 target

IDLE – GI~ 64% N_2, FI~ 68% N_2

MAX REV – max. reverse thrust. Doors cmd'd open when TLs at soft detent (TLA 14º)

- Cmds outboard spoiler panels to open when:
  - ➢TLA of both engines < 50º
  - ➢Flaps < 13º
- No intermediate positions
- Electrically controlled thru DC Bus 1 & 2
- Hydraulically actuated

If OEI or one reverser not deployed FADEC will only cmd reverse from good engine if TL requesting reverse and OEI TL set to IDLE

Thrust Lever Friction Knob

- Electrically actuated & controlled
- DC Bus 1 & 2
- If one channel fails, remaining motor can drive flaps at half speed
- 3º asymmetrical limit disables system for duration of flight

- Pulling actuates emergency brakes (no anti-skid)
- Pull & rotate to set parking brake
- Always have toe brakes applied when setting or releasing to prevent hydraulic fluid transfer
- All 4 brakes supplied by Hyd Sys 2 proportional to handle displacement with no protections

Thrust Mode select buttons (no ATTCS)

Joystick controls MFD designator

- Pedal brking
- Hyd Sys 1 supplies outbd brakes
- Hyd Sys 2 supples inbd brakes
- Anit-skid protection > 10 knots wheel speed
- Locked wheel protection through anti-skid system > 30 knots wheel speed
- Touchdown protection allows braking 3 seconds after touchdown, or when wheel speed ≯ 50 knots.

- With control column held full back, momentary push actuates SPS test *(stick shaker, clacker, & stick pusher)*
- TEST button illuminated after an unsuccessful test or if system has not been tested.
- TEST button inhibited inflight till 30 sec. after landing, above 70 KIAS, or with gear not downlocked.
- Ice compensation of SPS inhibited for 5 min. after takeoff.
- Ice compensation reset if:
  - ➢airborne & flaps set to 45º. **SPS ICE SPEED** msg remains,or
  - ➢on ground after pressing TEST button. **SPS ICE SPEED** msg cleared.

- Cuts out SPS channel 1 or 2 in case of failure
- Striped bar in button when pressed

Pusher inhibited
On grnd (except for test)
- Below 0.5 G
- While Quick Disconnect button pressed
- < 200 ft if RA failed
- Any Cutout button pressed
- > 200 knots
- At least 1 channel inop

CON thrust if one of the following:
- >300 ft AFL & gear not locked down, or
- >1700 ft AFL

Limited to OEI only

CLB or **CRZ** thrust if one of the following:
- >500 ft AFL, gear not locked down, AEO, or
- >1700 ft AFL and AEO

- **TO** thrust
- T/O-1 for the EMB 145
- T/O RSV for the EMB 135/140

May 2008 William de Groh

EMBRAER 145 FORWARD CENTER PEDESTAL

DAU 1: Forward aircraft & engine 1 parameters.
Ch A: Ess DC Bus 1 & Backup Ess Bus (default)
Ch B: DC Bus 1

DAU 2: Aft aircraft & engine 2 parameters.
Ch A: Ess DC Bus 2 & Backup Ess Bus (default)
Ch B: DC Bus 2

Radio Management Unit (RMU)

•Pressing allows Data Acquisition Unit (DAU) Channel B to supply both IC-600

•Striped bar in button when pressed



First press: Splits the NAV window into two windows. Top window displays active VOR frequency. The lower window, with the DME Label, displays the active DME frequency in VHF format. An H (DME Hold) is displayed in the DME window and on the PFD to show DME not paired with active VOR/ILS freq. The DME may then be tuned directly by pressing the LSK beside the DME window.

Second press: Displays the TACAN channel format and will allow tuning to the DME portion of any TACAN station.

Third press: Reverts NAV window to normal DME operation.

NORM – RMU tuning available

EMERG – tuning through RMU inhibited

Tuning Backup Control Head (TBCH)

Allows alternative means of tuning Com 2 and Nav 2

Activates internal self-test of component selected with yellow cursor box.

COM transceiver – Hold button 2 sec.

DME, ATC, and ADF – Hold for 5 to 7 sec.

NAV (VOR/ILS) – Hold for 20 sec.

C. APPENDIX C – PARTICIPANT INFORMATION SHEET

Dear Participant,

Re: Participation in Research on pilot eye tracking during flight

Thank you for offering to participate in my research project.

I am a part-time MSc student in the School of Mechanical, Industrial and Aeronautical Engineering at the University of the Witwatersrand, under the supervision of Mr Dieter Hartmann. My MSc title is: Eye-tracking of pilots during flight.

My belief is that there may need to be a change to the cockpit layout, so I am trying to determine whether the instruments need to be in different positions for the various stages of flight. This will be analysed after monitoring eye movements. The study will be conducted on [DATE]. Involvement in the study would entail a single simulator testing session in which you will have to fly while wearing a pair of eye-tracking glasses. During the session, I will be recording your eye movements while you fly. I would like it if you could be as natural as possible, forgetting that we are recording your eye movements to ensure we get accurate data. Participation in the study is voluntary, and you may withdraw at any time. Anonymity and confidentiality of information provided will be assured and respected. Your consent at the time of the interview will be requested. If you do not wish to participate, this will be respected. Please note, any data recorded during the study will be completely anonymous and raw data will only be available to the researcher and her supervisor.

The results of the study will form part of my MSc dissertation report, and may also be reported in academic papers and at conferences. A summary of the results of the research will be made available to you on request.

Please contact me if you have any questions regarding the research and participation in the study.

I look forward to hearing from you.

Jadine Inkley

D. APPENDIX D – LETTER OF CONSENT

I, _____, agree to participate in the MSc research entitled Eye-tracking of Pilots during flight, to be undertaken by Jadine Inkley under the supervision of Mr Dieter Hartmann, and certify that I have received a copy of this letter of consent.

I acknowledge that the research has been explained to me and I understand what it entails, as follows:

1. I agree to participate in the pilot eye-tracking study.
2. There will be a single testing session during which my eye movements will be recorded.
3. I will try to not obscure any results.
4. A second researcher, eye tracking equipment expert, will accompany the researcher during the session.
5. I have the right to withdraw my assistance from this project at any time without penalty, even after signing the letter of consent.
6. I have the right to refuse to answer one or more of the questions without penalty and may continue to be a part of the study.
7. I may request a report summary, which will come as a result of this study.
8. I am entirely free to discuss issues and will not be in any way coerced into providing information that is confidential or of a sensitive nature.
9. Pseudonyms will be used to conceal my identity, and that of my company and my employers. The information disclosed in the sessions will be confidential.
10. Recordings and transcripts will be kept securely stored during the research and after the research has been completed.
11. This project was approved by the Faculty of Engineering and the Built Environment of the University of the Witwatersrand and the School of Mechanical, Industrial and Aeronautical Research Ethics Committee (non-medical) of the University.
12. If I have any questions or concerns about my rights or treatment as a participant, I may contact the Chair of the School of Mechanical, Industrial and Aeronautical Research Ethics Committee (non-medical) at (phone #) or by (email).

Signed: _____

Date: _____

Questions concerning the study can be directed to:

Jadine Inkley

E. APPENDIX E – VALIDATION OF DATA

E.1 Prepared Runway Approach and Landing

A total of 17 prepared runway landings were recorded. Each of these landings were analysed using six AOIs, and their dwell times, percentage dwell times, fixation count and fixation rate for each landing were compared against each other using a Tukey's multiple comparison test (alpha = 5%, number of families = 6, number of comparisons per family for prepared runway landings = 120).

E.1.1 Prepared Runway Dwell Time per AOI visit

Figure E.1 below shows the prepared runway dwell time per AOI visit for each AOI. The values have been averaged and the standard deviation of each is shown.

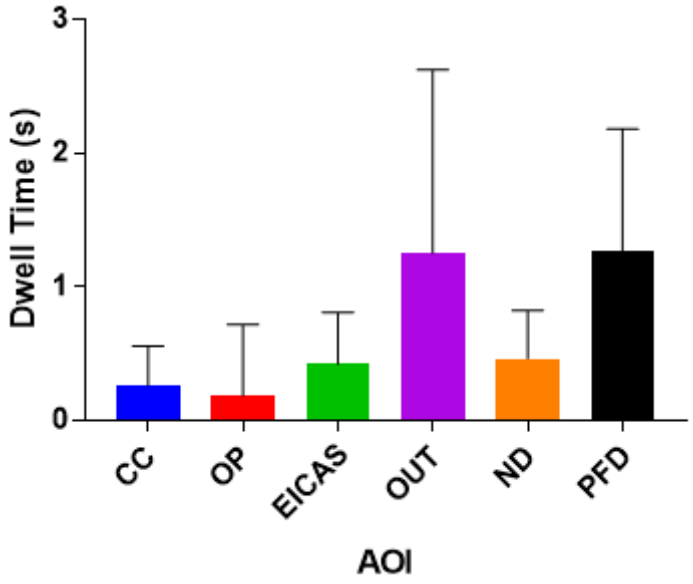


Figure E.1: Prepared runway dwell times per AOI.

A two-way ANOVA was conducted on this data and it was found that there was no significant variance between the pilots for each AOI (P value = 0.9058,) but there was a significance between the AOIs (P value <0.0001). When comparing the dwell times of

the landings using Tukey's multiple comparison test, most comparisons came out insignificant except for the following:

OUT AOI	P - Value
A1 vs B1	0.0004
A2 vs B1	0.0119
A3 vs B1	0.0166
B1 vs B2	0.0014
B1 vs B3	0.0031
B1 vs B4	0.0007
B1 vs B5	0.0012
B1 vs C2	0.0005
B1 vs D1	0.0010
B1 vs D2	0.0058
B1 vs E1	0.0035
B1 vs G2	0.0232
B1 vs G3	0.0019

E.1.2 Prepared Runway Percentage Dwell Time

Figure E.2 below shows the prepared runway percentage dwell times for each AOI. The values have been averaged and the standard deviation of each is shown.

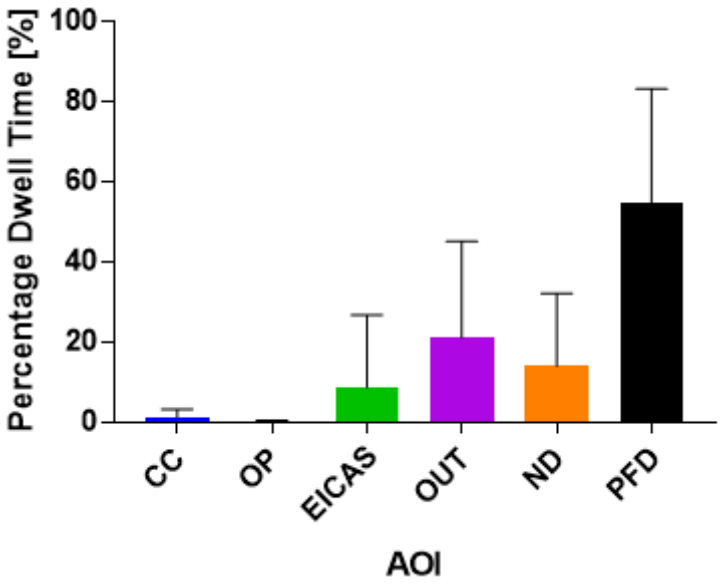


Figure E.2: Prepared runway percentage dwell times per AOI.

When comparing the percentage dwell times of the landings using Tukey's multiple comparison test, there was no significance between any of the pilots.

E.1.3 Prepared Runway Fixation Count

Figure E.3 below shows the prepared runway fixation count for each AOI. The values have been averaged and the standard deviation of each is shown.

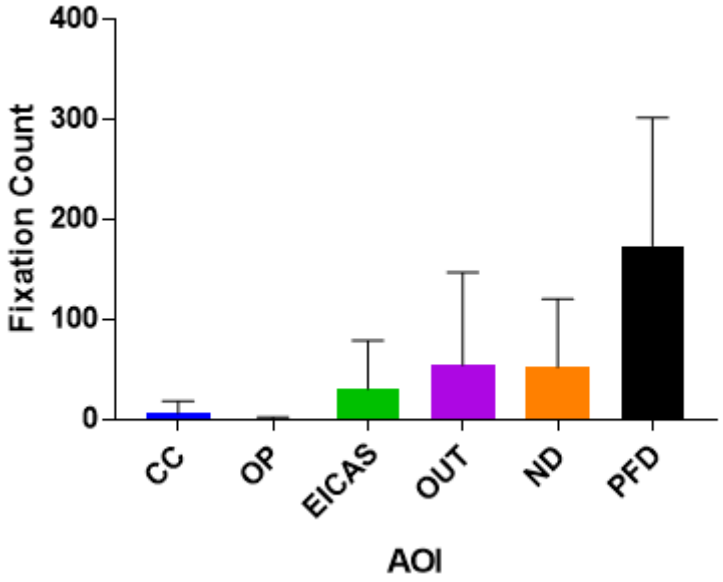


Figure E.3: Prepared runway fixation count per AOI.

When comparing the fixation count of the landings using Tukey's multiple comparison test, most comparisons came out insignificant except for the following:

OUT AOI	**P - Value**
A1 vs A2	0.0438
A2 vs B2	0.0462
A2 vs B4	0.0462
A2 vs B5	0.0474
A2 vs C2	0.0499
A2 vs D1	0.0474
PFD AOI	
A1 vs A2	0.0062
A1 vs B1	0.0062
A1 vs D1	0.0112
A1 vs G1	0.0325

E.1.4 Prepared Runway Fixation Rate

Figure E.4 below shows the prepared runway fixation rate for each AOI. The values have been averaged and the standard deviation of each is shown.

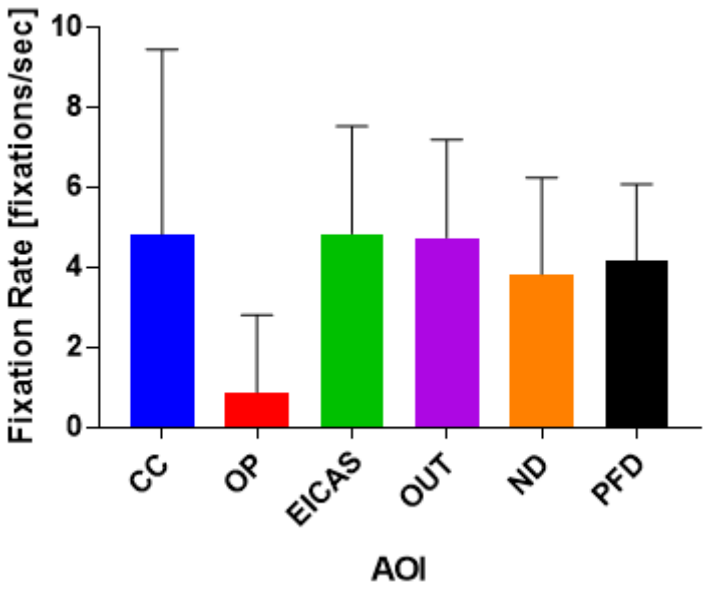


Figure E.4: Prepared runway fixation rate per AOI.

When comparing the fixation rate of the landings using Tukey's multiple comparison test, most comparisons came out insignificant except for the following:

CC AOI	**P - Value**
B1 vs C2	0.0106
B2 vs C2	0.0106
C2 vs D2	0.0106
C2 vs G1	0.0106
C2 vs G2	0.0106
C2 vs G3	0.0106

E.2 Unprepared Runway Approach and Landing

A total of 7 unprepared runway landings were recorded. Each of these landings were analysed using six AOIs, and their dwell times, percentage dwell times, fixation count and fixation rate for each landing were compared against each other using a Tukey's

multiple comparison test (alpha = 5%, number of families = 6, number of comparisons per family for unprepared runway landings = 21)

E.2.1 Unprepared Runway Dwell Time

Figure E.5 below shows the unprepared runway dwell times for each AOI. The values have been averaged and the standard deviation of each is shown.

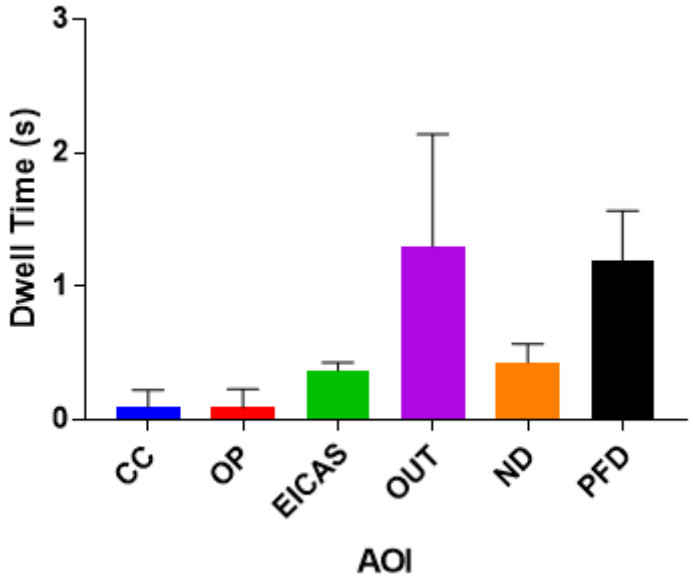


Figure E.5: Unprepared runway dwell times per AOI.

When comparing the dwell times of the landings using Tukey's multiple comparison test, most comparisons came out insignificant except for the following:

OUT AOI	**P - Value**
A4 vs J1	0.0326
I1 vs J1	0.0092
I2 vs J1	0.0042
I2 vs J3	0.0425
I3 vs J1	0.0028
I3 vs J3	0.0302

E.2.2 Unprepared Runway Percentage Dwell Time

Figure E.6 below shows the unprepared runway percentage dwell times for each AOI. The values have been averaged and the standard deviation of each is shown.

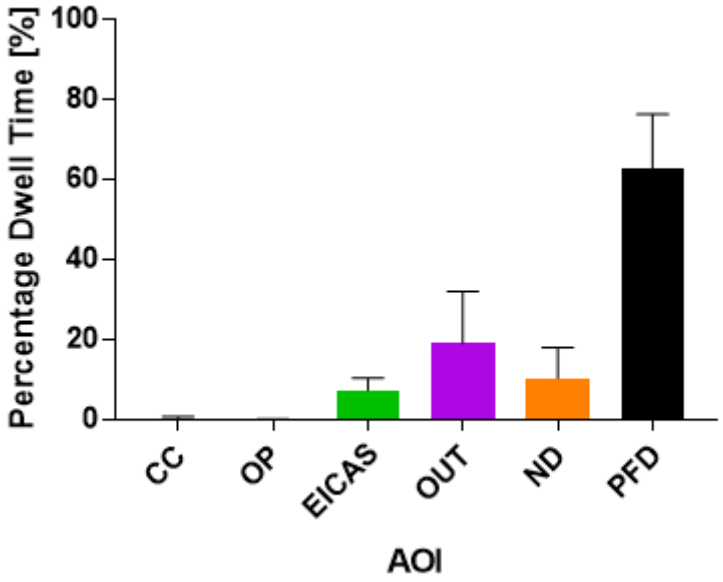


Figure E.6: Unprepared runway percentage dwell times per AOI.

When comparing the percentage dwell times of the landings using Tukey's multiple comparison test, there was no significance between any of the pilots.

E.2.3 Unprepared Runway Fixation Count

Figure E.7 below shows the unprepared runway fixation count for each AOI. The values have been averaged and the standard deviation of each is shown.

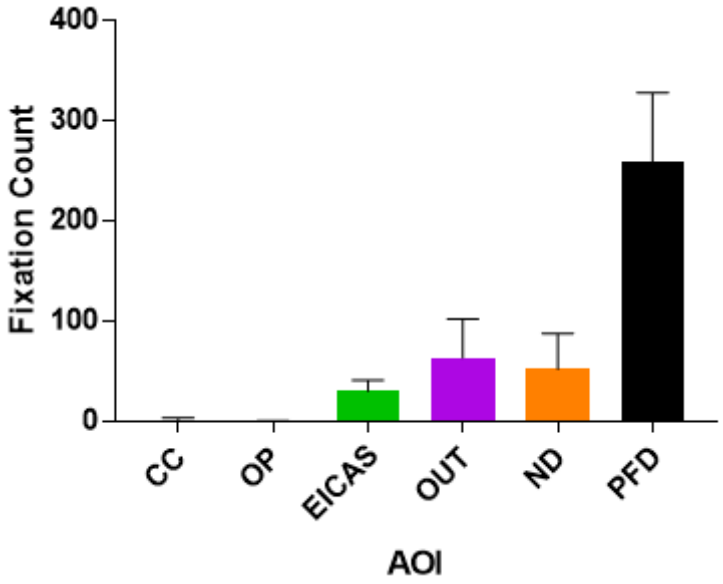


Figure E.7: Unprepared runway fixation count per AOI.

When comparing the fixation count of the landings using Tukey's multiple comparison test, most comparisons came out insignificant except for the following:

PFD AOI	**P - Value**
A4 vs I3	0.0095
A4 vs J1	0.0334

E.2.4 Unprepared Runway Fixation Rate

Figure E.8 below shows the unprepared runway fixation rate for each AOI. The values have been averaged and the standard deviation of each is shown.

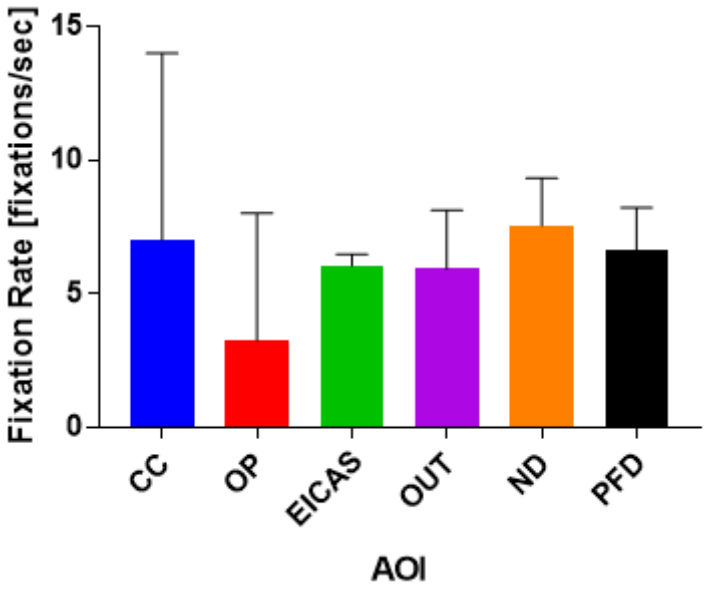


Figure E.8: Unprepared runway fixation rate per AOI.

When comparing the fixation rate of the landings using Tukey's multiple comparison test, most comparisons came out insignificant except for the following:

CC AOI	**P - Value**
A4 vs I1	0.0470
A4 vs J2	0.0455
I1 vs I3	0.0470
I1 vs J3	0.0470
I3 vs J2	0.0455
J2 vs J3	0.0455