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HEALTH & SAFETY LABORATORY

HSL Laboratory Report [Reactive]

Unit: Human Science Unit

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Review of human reaction times in respect to hydraulic door closing incident at Foodles Productions (UK) Ltd

1 INTRODUCTION

1.1 BACKGROUND

The Health and Safety Laboratory (HSL) were requested by Mr Mike Gray, HM Principal Specialist Inspector of Health and Safety on behalf of Mr Graham Tompkins, HM Inspector of Health and Safety, to provide an independent expert opinion in relation to an incident at Pinewood Studios on 12th June 2014 concerning Foodles Productions (UK) Limited.

1.2 ISSUES TO BE ADDRESSED

I was requested by Mr Tompkins to provide an opinion on the following issues:

- How fast an operator could be expected to react to an event;
- The effect that an unexpected, emergency event could have on reactions times; and
- The effect that training and practice could be expected to have on reaction times.

1.3 DOCUMENTS RECEIVED

I received a number of documents in relation to this incident. These are listed below.

- Received from Mr Graham Tompkins, HM Inspector of Health and Safety by email on 6th March 2015:
    - HSE Statement of witness – [redacted] dated 19th June 2014 (SoW PN)
    - HSE Statement of witness – [redacted] dated 19th June 2014 (SoW PT)
    - Photograph P1000914.jpg (G. Tompkins 13/6/14) – showing the door and the blue dummy button
    - Photograph P1000918.jpg (G. Tompkins 13/6/14) – showing the Operator monitor and the view of the door provided by the CCTV witness camera

- Received from Graham White, HSL Engineering and Personal Safety Unit
    - HSL Incident report ES/2014/88 - Hydraulically Operated Door Incident, Pinewood Studios, Buckinghamshire – Assessment of Closing Forces
    - HSL Sample ID 12864 – DVD of images and videos PH04765 Hydraulic door incident. Images used :
        - Photograph P1000657.jpg (D. Schofield 21/7/14) – showing the door way and the blue dummy door close button
        - Photograph P1000663.jpg (D. Schofield 21/7/14) – showing the position of the emergency stop button for the operator
        - Video footage P1000671.mp4 (D. Schofield 21/7/14) –showing door closure

1.4 UNDERSTANDING OF THE INCIDENT

My understanding of the incident is based on information received from Mr Graham Tompkins in a telephone conversation on 25th February 2015, and from documents, witness statements and photographs received from Mr Tompkins in emails on 6th March 2015. My understanding is that:

- The injured party (IP) was an actor who was injured when a hydraulically operated door, which was part of the film set, closed whilst the IP was in the doorway, knocking him to the ground. The IP sustained a serious break to his ankle.

- The door closed almost vertically, from the top, moving at a speed of approximately 2 metres per second, taking approximately 1.2 seconds to close fully and with a force of approximately one tonne. Following activation of the emergency stop button the door took 0.2 seconds to stop moving. Photograph 1 shows the door in question (open) with the ramp leading up to the door. Photograph 2 shows a closer view of the blue dummy button.

- Door closure was initiated by an operator via a laptop computer positioned out of direct line of sight of the door itself. The door could be viewed via a monitor beside the laptop controlling the door mechanism and enabled the operator to have a partial view of the actors by the door as shown in Photograph 3. The cues for the operator to close the door were seeing the actor pressing a blue dummy button on the inside of the door (see Photographs 1 and 2) and a verbal cue from the Special Effects Supervisor via a radio microphone and head-set.

- The supervisor was sitting on the floor facing the door, holding the emergency stop button in one hand with the other hand over the button (SoW PN). [redacted]

- The operator had an emergency stop button to stop the door, next to [redacted]r laptop (as shown in Photograph 4). [redacted].

- Both the operator and supervisor were aware of the risk of serious injury or fatality associated with the door closing onto a person (SoW PN, SoW PT).

- Previous rehearsals of the scene that day had been carried out without the door being closed. The supervisor was told that the door was to be activated for the first full costume rehearsal and passed this message to the operator. For the first rehearsal, the special effects team were not ready to activate the door so the door was not closed when the IP pressed the blue dummy button the first time. The IP then stepped away from the door.

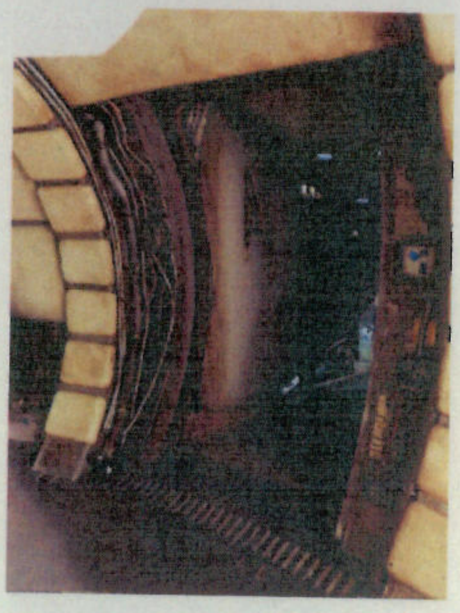
- The supervisor asked the operator if [redacted] was ready to activate the door and [redacted] The IP approached the door again and pressed the blue button. The supervisor gave the operator the verbal cue to close the door (SoW PN). On receiving both visual and verbal cues, the operator pressed the key on the laptop computer to initiate the door closure SoW PT).

- After pressing the dummy button the second time, the IP turned towards the door to go back down the ramp, as the door was closing. It struck him in the region of his head and knocked him to the ground beneath the door. The IP's height was estimated at 1800 mm.

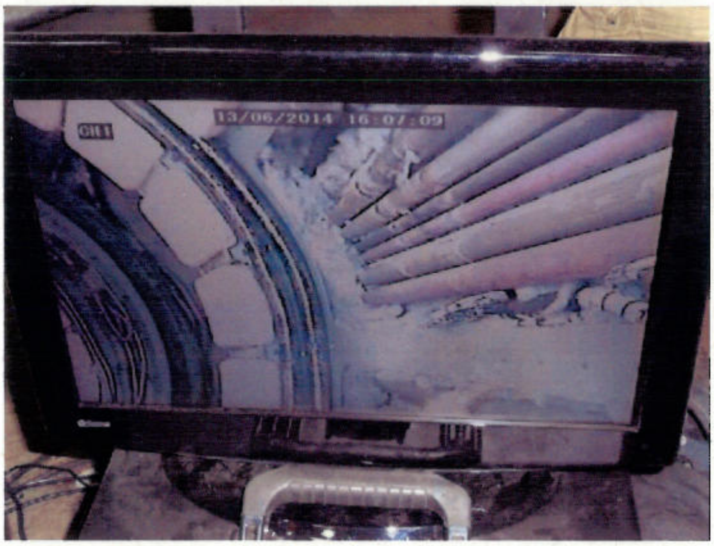
- The door was stopped from closing completely when an emergency stop button was pressed by either the supervisor or the operator. [redacted] then move back into view and saw the door strike the IP's head before he went backwards and out of view. [redacted] heard a scream and [redacted] hit [redacted] emergency stop button (SoW PT).

- The door stopped with the bottom edge approximately 178-203 mm from the floor with the IP lying on the ground underneath the edge of the door.

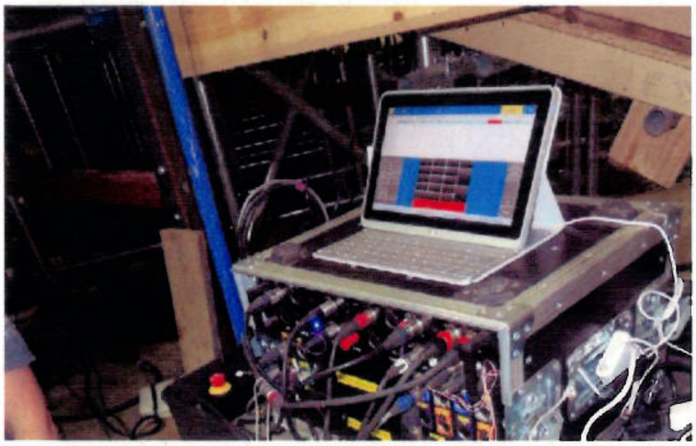
Photograph 1 View of door way (door open) (P1000657.jpg)



Photograph 2 Close up view of door (door open) showing view down ramp and blue dummy button to right of door (P1000914.jpg)



Photograph 3 Monitor used by door operator showing view of door provided by the witness camera (P1000918.jpg)



Photograph 4 Laptop set up used by operator to activate door closure showing position of red emergency stop button (bottom left) (P1000663.jpg)

1.5 BRIEF OUTLINE OF EXPERTISE

I am a Senior Ergonomist working for the Health and Safety Laboratory (HSL). HSL is the research agency of the Health and Safety Executive (HSE). I have been employed by HSL for 9 years as an Ergonomist. During this time I have carried out research and incident investigations for HSE in the area of human factors and ergonomics. I have a BSc (Hons) in Occupational Therapy from Derby University (1996) and an MSc (Distinction) in Ergonomics from Loughborough University (2004). I am a Registered Member of the Chartered Institute of Ergonomics and Human Factors (CIEHF).

1.6 APPROACH USED

To address the issues, a literature review has been carried out to consider human reaction times to signals and events. The HSE Information Service Search Team were asked to carry out a keyword search of a number of relevant psychology and human factors databases. The keywords were supplied by myself and covered terms associated with human reaction times in emergency, unexpected or surprise situations. The key words used for the literature search are provided in the Appendix of this report.

In addition, I reviewed the witness statements, photographs and other documents listed previously to provide me with an understanding of the circumstances surrounding the incident.

2 REVIEW OF HUMAN REACTION TIMES

2.1 WHAT IS HUMAN REACTION OR RESPONSE TIME?

Research suggests that human reaction or response time to a sensory signal (usually visual or auditory) is made up of three components which occur in sequence. These components are generally referred to in the literature as perception (or mental processing time), movement time and device response time. These components are explained in more detail below:

1. **Perception time**
   This is also referred to as mental processing time and is defined as the time that it takes for a person to perceive that a signal or event has occurred and to make the decision to respond. Perception time can be further broken down into the following:
   a. Detection of the signal – the signal or event must first be seen or heard by the person
   b. Perception – this is the time the person takes to recognise the meaning of the signal
   c. Response selection –this is the time necessary for the person to decide how to respond, what action to take.
2. **Movement time** – this is the time it takes for the person's muscles to perform the movements required to take the action that has been decided on within the response selection time e.g. lifting the hand from its resting position, placing it on the emergency stop button and applying force to engage the button.
3. **Device response time** – this is the time it takes for the physical device to perform its response, e.g. the time it takes for the door to stop once the emergency stop button has been activated.
   (Green, 2000)

Device response time is usually excluded from studies where this is not virtually instantaneous, such as for vehicle braking when the time taken for the brakes to slow or stop the car can be several seconds depending on the speed of travel, tyres, road surface etc. These studies refer to brake reaction time as being from the signal point to the point where the brake pedal is first pressed and total stopping time where the device response time is included. For the purposes of this report, I will refer to reaction time, in the context of the incident, as the combination of mental processing time and movement time, and total response time where the device response time (i.e. the time for the door to stop moving following activation of the emergency stop) is included.

2.2 RELEVANT STUDIES

Whilst no studies were found that entirely match the circumstances of the incident, a number of studies were identified that I consider to be relevant. The studies most relevant for reaction times to emergency situations involve vehicle drivers braking in response to emergency events (such as sudden application of brake lights in vehicle in front, obstacles in road, stop signals); and emergency stopping of industrial robots operating in the vicinity of humans. These scenarios involve the components of the incident, which include:

- Monitoring and maintaining attention to the surroundings and situations;
- The detection and perception of a visual signal for an unexpected, low probability event requiring an urgent, emergency response;
- A small number of possible responses to choose between, and;
- Small movements of the hand/arm or foot/leg to initiate response the response.

For comparison purposes, I have also included studies of simple reaction times as these studies found the fastest human reaction times.

2.3 HUMAN REACTION TIMES FOR SIMPLE REACTIONS TO SIGNALS

The review of the literature identified that the fastest human responses that are possible to achieve are simple reaction times. Simple reaction time refers to scenarios where the person is fully expecting the signal, is aware of what the signal will be and where there is only one response available. Studies of simple reaction time often involve subjects sitting with their finger on a button or lever and responding as fast as possible to an expected (and repeated) signal which is usually a light or a sound. Simple reaction times are the fastest human reaction times reported in the studies because the perception time is short as the signal, its meaning and the response decision require little mental processing. In addition, both the movement time and device response time are short.

The literature suggests that response times for human reaction to an expected and anticipated signal, requiring a highly practised single response, and minimum movement to activate the response (e.g. the finger is resting on the key to be pressed) range between 0.15 and 0.25 seconds (Table 6 in Appendix).

2.4 REACTION TIMES FOR UNEXPECTED, EMERGENCY EVENTS

The incident concerned did not involve an expected, commonly repeated event, with no perceived risk or adverse consequence to either the participant or anyone else, as described for the simple reaction time studies. The incident was dissimilar in that it involved an unexpected, un-common event with the potential for injury to others.

Studies on braking reaction times in driving experiments provide some indication of the likely effect of unexpected, emergency events on reactions times. The review of the literature found a large variation in brake reaction times reported in the studies. The studies concerning braking reaction times fall broadly into three groups:

1) Studies where the signal is expected and is a common signal for drivers (e.g. braking for a red traffic light or braking when the car in front puts its brake lights on).
2) Studies where the driver knows that he/she will be required to respond and what the signal will be, but not whether that response will be required imminently.
3) Studies where the event signal is unexpected and not common for driving i.e. the event is a surprise (e.g. an obstacle in the vehicle path, a barrel rolled in front of the vehicle).

The only studies identified in the literature review that concerned reaction times for a person activating an emergency stop button in response to a signal involved the use of industrial robots.

2.4.1 Braking reaction times for expected signals

Braking reaction time studies for expected signals are those where the subjects were told that they would be required to brake imminently and what the signal would be, so they are expecting to have to brake. One review of braking reaction times suggests that there is broad agreement in the literature that a mean brake reaction time for expected events in road tests is around 0.7-0.75

seconds, consisting of 0.5 – 0.55 seconds of perception time and 0.2 seconds of movement time (time to lift foot off accelerator and onto brake pedal) (Green, 2000). The brake reaction times for expected signals reviewed for this report were in the range of 0.4 – 1.0 seconds (Table 7 in Appendix).

2.4.2 Braking reaction times for unexpected braking studies

Braking reaction time studies for unexpected signals include those where subjects were not specifically told that the need to brake was imminent so the timing of the signal was more uncertain. The signal in these studies was common for experienced drivers (e.g. an obstacle in the road ahead, brake lights illuminating on the vehicle in front). The mean brake reaction times found in these studies varied quite widely between 0.678 - 1.4 seconds (Table 8 in Appendix). In his review, Green (2000) suggests that the best estimate of brake reaction time in response to common but uncertain signals lies between 1.2 and 1.35 seconds. It is suggested in the literature that the increased brake reaction times for unexpected events is due to the longer time needed to detect, recognise the signal and decide how to respond than when the response is expected.

2.4.3 Braking reaction times for surprise event braking studies

It is acknowledged to be difficult to simulate truly surprising and unusual events under experimental conditions, as the very nature of taking part in an experiment is likely to increase anticipation that something unusual is going to happen at some point. One review suggests that brake reaction times to surprise (unexpected and low probability) events may be longer than those for unexpected but common signals and suggests reaction times of 1.5 seconds are likely (Green, 2000). However, Green's estimate of 1.5 seconds for surprise braking reactions times has been criticised by other authors for not taking into consideration the urgency factor. It is suggested that drivers will respond faster when they perceive that they are on a collision course with another vehicle or obstacle and that they have to take action immediately and abruptly to avoid that collision i.e. in short time-to-collision scenarios (Summala, 2000).

Summala (2000) suggests that average brake reaction times for extremely urgent situations, where the time-to-collision is very short and hard braking is required, would vary between 0.86 and 1.39 seconds. In the review for this report, braking reaction times for surprise events ranged from 0.65 – 1.8 seconds (Table 9 in Appendix). The fastest foot brake reaction times in the studies reviewed for this report were 0.65 seconds, reported by Dingus et al (1998) for studies into emergency situations where a barrel was fired into the path of the vehicle without warning.

2.4.4 Reactions times for emergency stopping industrial robots

Three studies were identified where the movement time or reaction time to pressing an emergency stop button were measured. These all concerned the emergency stopping of industrial robots where they were in use in proximity to people. However, only one of these studies measured reaction time from the occurrence of the signal to the response (pressing the hand held emergency stop button). The other two studies measured movement time from lifting fingers from the face of the hand held control pendant to pressing the stop button on the pendant. These studies required participants to monitor the robot as it carried out a task and press a hand held emergency button when they detected an error such as an unexpected movement of the robot arm. As such, the signal was unexpected in that the exact timing of it was uncertain although the signal itself was known and anticipated, and there was no risk of injury (or perception of risk) involved if the robot was not stopped quickly. Device response time was not included in these studies.

The study looking at the reaction time from detection of an overrun of a robot arm moving at set speeds to the pressing of a palm held emergency stop button found a mean reaction time in a range of 0.3 – 0.54 seconds depending on the speed the robot arm was moving (Etherton and Sneckenberger (1990) (Table 10 in Appendix). The fastest mean reaction time was 0.3 seconds for a robot arm moving at 450 mm/second. The study concludes that reactions to objects moving at higher speeds were found to be faster and probably closer to reflex movements.

The two studies looking at movement times to press an emergency stop button on a hand held control pendant found that the movement time ranged from 0.11 – 0.2 seconds depending on the size and position of the emergency stop button (Table 10 in Appendix). This suggests that the movement time for pressing an emergency button where the hand is in very close proximity to the button may be shorter than the movement times found for foot movements in the brake reaction time studies.

2.5 SUMMARY OF REACTION TIMES

The fastest human reaction times were found in studies looking at simple reaction times for expected signals. Vehicle braking studies considered brake reaction times to unexpected and emergency events. In the studies reviewed for this report a wide range of brake reaction times, from 0.65 to 1.8 seconds, was identified. There is a large variation in brake reaction times depending on expectation of the event or signal, whether the event is common, time-to-collision (urgency), and individual factors such as age, gender, driving experience, attention/distraction as well as the type and methodology of the study. The key points from the reaction time studies are:

- For simple reactions where the signal is expected and anticipated, requires a highly practised single response, and minimum movement time, the reaction times range between 0.15 and 0.25 seconds.
- For brake reaction times in response to a signal that is expected and common, the mean brake reaction time is likely to be about 0.7 – 0.75 seconds (although some simulator studies have recorded braking reactions as quick as 0.4 seconds).
- For brake reactions where the signal is unexpected but common, the studies suggest that the best estimate is likely to be between 1.2 – 1.35 seconds.
- Where the signal is unexpected and of low probability but with several seconds time-to-collision, then some studies have found the brake reaction time to be slower at around 1.5 seconds.
- For brake reaction where the signal is unexpected, a surprise and time-to-collision is very short, some studies have found faster brake reaction times, as low as 0.65 seconds.
- For foot braking, movement times (from lifting the foot off the accelerator to pressing the brake pedal) average 0.2 seconds and range from 0.17 – 0.3 seconds.
- The brake reaction times do not include the time it takes to stop or slow the car (device response times), only the time from the signal being presented to the start of pressing the brake pedal or other response.
- For emergency stopping of industrial robots, one study found the reaction time from detection of an overrun of a robot arm to the pressing of a palm held emergency stop button to be in the range of 0.3 – 0.54 seconds.
- Movement times to press an emergency stop button on a hand held control pendant were found to range from 0.11 – 0.2 seconds depending on the size and position of the emergency stop button.

2.6 OPINION ON REACTION TIMES MOST APPLICABLE TO THE INCIDENT

In my opinion, the circumstances of the incident concerned would be considered as a low probability and critical event requiring an urgent response and as such would perhaps fit best within the category of brake reaction times for unexpected, surprise and urgent events (0.65-1.8 seconds). Whilst the incident was not completely unexpected as the operator and supervisor were alert and watching for an event that may require the emergency stop to be activated, it was not something that had happened frequently and it required an immediate, urgent reaction due to the risk of serious injury of which they were aware.

2.7 EFFECT THAT AN UNEXPECTED, EMERGENCY EVENT COULD HAVE ON REACTIONS TIMES

Braking reaction time studies have generally found that novel events require extra processing time than common, usual events. Green (2000) suggests that longer processing times are required where, for example, a driver sees an unexpected shape in the road ahead, especially at night or where visibility is poor. Comparison of brake reaction times for unexpected but common signals (1.2 seconds) with the reaction times to unexpected and unusual events (1.5 seconds) supports this for situations where the time-to-collision is not very short. However, in extremely urgent, emergency situations the literature suggests that the urgency of the situation may shorten both the perception and the movement time components of the reaction time. Studies approximating emergency braking to surprise events have found braking reactions of 0.65 seconds which is closer to those generally found in braking for expected events (0.7 seconds).

This suggestion that reaction times to urgent events are faster than non-urgent events, is supported by the one industrial robot emergency stop study that looked at reactions times for overrun movements of the robot arm moving at different speeds. This study found that faster reaction times were recorded where the robot arm was moving faster, 0.3 seconds for robot speed of 450 mm/second compared to 0.4 for 250 mm/second (Etherton and Sneckenberger, 1990). However, whilst the timing of these overrun movements was uncertain, participants knew what movements they were looking for and were anticipating them so these are not unexpected, surprise events.

The evidence from the literature suggests that critical events requiring an emergency response where there is perceived risk of injury to self or others, are likely to generate faster reaction times than expected, anticipated, non-critical events. However, in the circumstances of the incident, in my opinion, the time taken to detect the unexpected movement of the IP (back towards the door rather than away from it) and then to understand what was happening, may not be offset by a faster reaction time for an urgent, critical event.

2.8 EFFECT ON REACTION TIMES OF PRACTICE / TRAINING

The literature reviewed yielded little information on how practice or training affects reaction times. Practice or training could be aimed at decreasing the perception time component of the signal or the movement time (or both).

For even relatively novice drivers, signals such as the brake lights illuminating on the vehicle in front, traffic lights changing or other vehicles pulling out in front, are familiar, commonly encountered events which drivers are well-practised at detecting, understanding and deciding how to respond to. The expectation would be that braking reaction times to these commonly encountered, practised signals would be shorter than reaction times to signals that are not usually encountered, such as objects in the middle of the road. As discussed above , comparison of brake reaction times for unexpected but common signals (1.2 seconds) with the fastest reaction times to unexpected and unusual events (1.5 seconds) supports this to some extent but where the signal requires an urgent, emergency response, the brake reaction times may be faster (e.g. 0.65 seconds). This suggests that the urgency or criticality of the event can have a have a greater effect in decreasing reaction times than being familiar and practised with the event.

It is acknowledged in the literature reviewed that the movement time component of reaction times may be decreased with practice of the movements (Green, 2000). However, the effect of movement practice is likely to be greater for foot braking than for pressing a button. This is because foot braking involves more complex movements, requiring some accuracy in lifting the foot from one pedal and moving it across and onto the brake pedal. In comparison, pressing a button, where the finger or hand is already positioned over the button, only requires a small movement in one direction.

For the two studies looking at movement to press an emergency stop button in response to unexpected movements of industrial robots, practicing detecting the signal and hitting the emergency button does not appear to decrease the movement time. In one study the participants practiced detecting the signal and pressing the emergency button 20 times before the start of the experiment and the fastest mean movement time achieved was 0.11 seconds (Collins, 1989). In the second study the detection of the signal and pressing the button were not practised and this study achieved similar mean movement times of 0.14 seconds (Kwon, 1996). Note that these are movement times and exclude the time taken to detect and process the signal.

2.9 EFFECT OF VIEW OF THE INCIDENT ON REACTION TIMES

At the time of the incident the supervisor and operator were not expecting the IP to move back towards the door once he had pressed the dummy button and the door closure had been activated. The evidence suggests that reaction times to unexpected events or signals are longer than for expected signals. This is because of the increased mental processing time needed to detect the unexpected signal (i.e. that the IP was moving back towards the door), to recognise that there is a risk that the door will strike the IP (perception time), and to decide how to respond (response selection time).

The view provided on the operator's monitor by the witness camera, as shown in Photograph 3, suggests that [redacted] was only able to see the head and upper body of the IP if he was standing close to the door. Once he stepped even a short distance away from the door it is likely that he would be out of view of the witness camera and he would not come back into view until he was within arms' reach of the door threshold. [redacted] This limited view of the door and the surrounding area is likely to increase the detection and mental processing components of the operator's reaction time. The literature suggests that perception time increases where signals are not clearly visible (Green, 2000).

The supervisor appears to have had a better view of the doorway and the movement of the IP and the area surrounding the door. [redacted]). I would expect his reaction time to be faster than that of the operator because his view of the IP was clearer and there was no suggestion that the IP moved out of his view or that he could not see his whole body which would be likely to facilitate the detection and recognition of the IP's movements. [redacted]). This is part of the mental processing component of reaction times.

3 EXPECTED REACTION TIMES FOR THE INCIDENT

3.1 REACTION TIMES FOR EMERGENCY STOP PRACTICE

[redacted]. I would expect the reaction times to these, non-emergency, anticipated events to be similar to those suggested for simple reactions i.e. 0.15-0.25 seconds (excluding the time it takes the door to stop after emergency stop activation). However, this does not reflect the incident scenario.

3.2 ESTIMATED REACTION TIMES AND TOTAL RESPONSE TIMES FOR INCIDENT

Table 1 uses the range of reaction times identified from the studies reviewed to estimate the reaction times that might be expected in the circumstances of this incident. For example, the range of reaction times for surprise, emergency braking found in the literature was 0.65 – 1.8 seconds. This includes an estimated 0.2 seconds of movement time of the foot from the accelerator to the brake pedal. However, hand movement time to press an emergency button, where the hand is held close to the button, have been found to be faster than foot movement time. Adjusting the brake reaction time to separate out the perception time from the movement time gives a range for the perception times of 0.45 – 1.6 seconds. The hand movement time for pressing an emergency button is estimated at 0.11 seconds. In addition, brake reaction times do not include the door response time which for this incident is the time it takes for the door to stop moving once the emergency stop button has been activated (0.2 seconds). Adding the door response time and the hand movement time to the perception time provides an estimate of the range of total response times that could be expected if the surprise, emergency braking reaction times are used as the basis for human reaction times in the circumstances of this incident. This gives an estimated range of total response times of 0.76 – 1.91 seconds.

Table 1 Estimated reaction times and total response times for stopping the door using the emergency stop button

Type of reaction time / range of reaction times found in review (secs)	*Perception time (secs)*	*Movement time for estop (secs)*	*Door response time (0.2 secs assumed)*	*Estimated total response time (reaction time plus door response time) (secs)*
Simple reaction time / 0.15 – 0.25	0.15 – 0.25	Included in perception time	0.2	0.35 – 0.55
Brake reaction to expected signals / 0.4 – 1.0*	0.2 -0.8	0.11	0.2	0.51-1.11
Brake reactions for unexpected signals/ 0.68 -1.4*	0.48 – 1.2	0.11	0.2	0.79 – 1.51
Brake reaction times to surprise, urgent signals / 0.65 – 1.8*	0.45 – 1.6	0.11	0.2	0.76 – 1.91
Unexpected movement of robot arm / 0.3 – 0.54	0.3 – 0.54	Included in perception time	0.2	0.5 – 0.74

*Assuming 0.2 secs of this is time to move foot from accelerator to brake pedal i.e. foot movement time.

3.3 DOOR CLOSURE

The information I received from Mr Tompkins, HSE Inspector and contained in the statements of witness, [redacted]. I was not able to obtain the vertical height of the door way from the tunnel floor to the bottom edge of the door in its fully open position. However, Mr Tompkins estimated this this was 2000 mm.

On viewing the video clip of the door closing (P100671.mp4), it appeared that the door did not close at a steady rate but closed faster initially then slowed considerably as the bottom of the door approached the tunnel floor. I viewed the video clip of the door closing at 80% of operating speed, frame by frame, to estimate the rate of closure. At this speed, I estimated from the video that the door closed in 1.6 seconds. This is taken from the first frame of the video that door movement can be identified to the last frame where the door moves. (The video is filmed at 25 frames per second). From still photographs captured from this video every 5 frames, which equates to 0.2 seconds, I estimated the percentage that the door had closed (Table 2). Photograph 5 shows the fully open door position, Photograph 6 shows the position of the door after 0.2 seconds and Photograph 7 shows the position after 0.4 seconds.

Table 2 Rate of door closure estimated from video (Door fully closed in 1.6 seconds)

Elapsed time from start of door closing (secs)	*Percentage closed (%)*	*Rate of closure in this time period (%)*	*Estimated vertical height of door edge from floor (mm)**
0.2	10	10	1800
0.4	33	22	1340
0.6	59	26	820
0.8	78	20	440
1.0	93	13	140
1.2	97	6	60
1.4	99	2	20
1.6	100	1	0

*Assuming door height of 2m

Photograph 5 Door fully open - 80% operating speed. (Frame 2537 P1000671)

Photograph 6 Door position after 0.2 seconds - 80% operating speed. (Frame 2542 P1000671)

Photograph 7 Door position after 0.4 seconds - 80% operating speed. (Frame 2547 P1000671)

From the video clip of the door closing at 80% of its operating speed, it can be seen that the door closes at a faster rate initially then slows. I would estimate that in the first half of the total closing time (0.8 seconds) the door has closed by more than 75% of the total closing distance. After 0.2 seconds, I would estimate the door to have closed by 10% and after 0.4 seconds by 33%. Assuming that the vertical height of the door when it is fully open is 2m, I have estimated the vertical height of the door edge from the tunnel floor at intervals of 0.2 seconds from the video clip (Table 2). This suggests that 0.2 seconds after the door starts moving, the bottom edge of the door would be approximately 1800 mm from the floor, and after 0.4 seconds, approximately 1340 mm from the floor. I understand that the IP's height was 1800 mm. This suggests that the IP could have been struck on the head by the closing door 0.2 seconds after the door edge started to move with the door closing at the speed in the video footage (full closure in 1.6 seconds).

3.3.1 Estimated door closure and total response times

Table 3 shows estimated times for the bottom edge of the door to reach a range of vertical heights from the tunnel floor assuming 2 m height when fully open, for a range of door closure speeds of between 1 and 2 seconds to fully close. These are estimated from the rates of closure from the video footage of the door closing at 80% of operating speed where the door closes fully in 1.6 seconds. This information is also shown in Figure 1. From this I would estimate that, if the door closed fully in 1.2 seconds as the information provided by Mr Tompkins states, rather than 1.6 seconds from my analysis of the video, then the door edge would reach 1800 mm (i.e. 10% closed) in 0.15 seconds and 1340 mm (33% closed) in 0.3 seconds.

Table 3 Estimated percentage door closure associated with different closure times (assuming same rate of closure from video (1.6 secs full closure)

*Percentage closed / Vertical height of bottom edge of door**	*Full closure in 1 sec (secs)*	*Full closure in 1.2 secs*	*Full closure in 1.6 secs*	*Full closure in 1.8 secs*	*Full closure in 2 secs*
10%/ 1800 mm	0.125	0.15	0.2	0.225	0.25
33% /1340 mm	0.25	0.3	0.4	0.45	0.5
59% / 820 mm	0.375	0.45	0.6	0.675	0.75
78% / 440 mm	0.5	0.6	0.8	0.9	1
93% / 140 mm	0.625	0.75	1	1.125	1.25
97% / 60 mm	0.75	0.9	1.2	1.35	1.5
99% / 20 mm	0.875	1.05	1.4	1.575	1.75
100% / 0mm	1	1.2	1.6	1.8	2

*Assuming door height of 2m

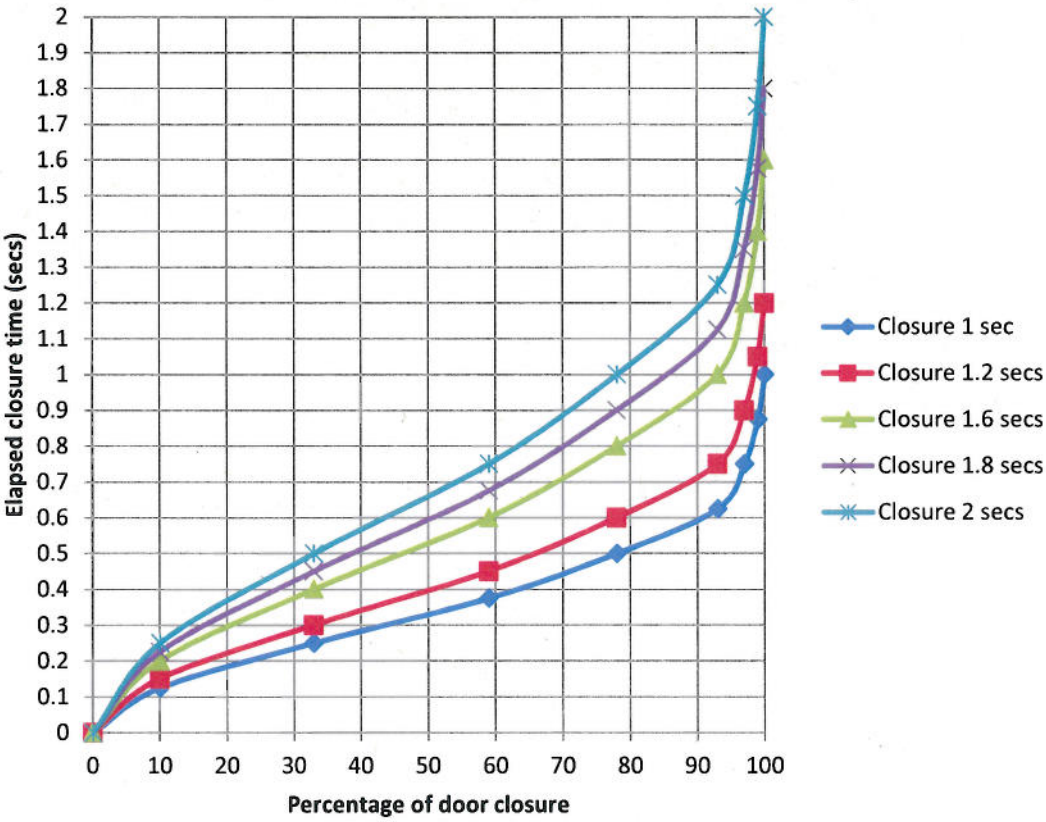


Figure 1 Estimated percentage door closure associated with different closure times

Applying the rate of closure indicated in Figure 1 to the total response times (reaction time plus door response time) estimated from the review, provides an approximation of the vertical height of the bottom edge of the door from the floor and the percentage of closure within that range of total response times, where the door is closing at different speeds (Table 4). This takes into account that the door closes at a faster rate initially so that in half of the time it takes to fully close, the door has closed by more than 75%.

This suggests that, using the fastest total response times (0.35-0.55 seconds) based on simple reaction times, the door would close approximately 40-70% assuming it was closing at a speed that would close fully in 1.2 seconds. This suggests that the bottom edge of the door could be between 1200 and 600 mm from the floor in this range of total response times. Similarly, at a door closure speed where the door is fully closed in 1.6 seconds, the door could close by 25-52% in this range of total response times which equates to the bottom edge of the door closing to a height of between 1500 and 960 mm.

Table 4 Estimated percentage door closure and height of bottom edge of door in total response times

Type of reaction time / range of reaction times found in review (secs)	*Estimated total response time (reaction time plus door response time) (secs)***	*Approx % door close in estimated total response time (assuming 1.2 secs to close fully)****	*Approx % door close in estimated total response time (assuming 1.6 secs to fully close)****
Simple reaction time / 0.15 – 0.25	0.35 – 0.55	40-70% (Door height 1200 – 600 mm)	25-52% (Door height 1500 – 960 mm)
Brake reaction to expected signals / 0.4 – 1.0*	0.51-1.11	68-98% (Door height 640-40 mm)	48-95% (Door height 1040 – 100 mm)
Brake reactions for unexpected signals/ 0.68 -1.4*	0.79 – 1.51	94% to fully closed (Door height 140 – 0 mm)	77- 99% (Door height 460-20 mm)
Brake reaction times to surprise, urgent signals / 0.65 – 1.8*	0.76 – 1.91	93% to fully closed (Door height 140 - 0 mm)	75% to fully closed (Door height 500 - 0 mm)
Unexpected movement of robot arm / 0.3 – 0.54	0.5 – 0.74	64 – 92% (Door height 720 - 160 mm)	45-73% (Door height 1100 540 mm)

*Assuming 0.2 secs of this is time to move foot from accelerator to brake pedal i.e. foot movement time.
** Assuming 0.2 secs door response time
***Assuming vertical height of door when fully open is 2m

Anthropometric data indicates that only 1.5% of the United Kingdom (UK) adult population are under 1500 mm in stature (Peoplesize, 2008). This suggests that 98.5% would have been struck on the head by a door at a height of 1500mm before it could stopped by activating an emergency stop button given the fastest estimated total response time (0.35 seconds) at a speed of 1.6 seconds to fully close. For the same total response time with the faster door speed of full closure in 1.2 seconds, less than 0.01% of the UK adult population would be protected as the door would have closed to a lower height of 1200 mm.

I understand that the IP's height was 1800 mm. Analysis of the video footage indicated that 0.2 seconds after the door started moving, the bottom edge of the door was approximately 1800 mm from the floor. In my opinion, this suggests that the IP could have been struck on the head by the closing door 0.2 seconds after the door edge started to move with the door closing at the speed in the video footage (full closure in 1.6 seconds). To prevent this happening, the emergency stop operators would have had to stop the door in less than 0.2 seconds which (assuming the door response delay is 0.2 seconds) would mean that they would have had to anticipate that the IP was moving back towards the door and press the emergency stop button before the door started to move. This, in my opinion, is unlikely to be achievable.

It is my opinion that, in the circumstances of this incident, the total response times that are likely to be achieved would be closest to the range suggested by studies into brake reaction times to surprise, urgent signals which is 0.76 – 1.91 seconds (including 0.2 seconds assumed delay for the door to stop moving following an emergency stop activation). Using this range of total response times, I would estimate that the door (assuming a closing time of 1.6 seconds) could be between 75% to 100% closed (500 – 0 mm door height).

My understanding of the incident is that either the supervisor or the operator activated an emergency stop button and the door stopped with the bottom edge approximately 178-203 mm from the tunnel floor. Assuming a door height of 2 m, I estimate that the door was approximately 90% closed when it was stopped. This is in line with the 75% -100% estimation of door closure based on the reaction times found for surprise, urgent braking events, assuming a closing time of

1.6 seconds and slightly better than the estimated door closure (93% to fully closed) assuming a faster closing time of 1.2 seconds.

4 CONCLUSIONS

The incident occurred at Pinewood Studios on 12th June 2014. An actor was injured during film rehearsals, when a hydraulically operated door, which was part of the film set, closed as he was attempting to go through the doorway, knocking him to the ground. Following this incident independent, expert opinion was requested regarding the following issues:

- How fast an operator could be expected to react to an event;
- The effect that an unexpected, emergency event could have on reactions times; and
- The effect that training and practice could be expected to have on reaction times.

4.1 OPINION ON HOW FAST AN OPERATOR COULD BE EXPECTED TO REACT TO AN EVENT

The fastest human reaction times that are possible to achieve are simple reaction times where the person is fully expecting the signal, is aware of what the signal will be and where there is only one response available. Reaction times in these circumstances are usually in the region of 0.15 – 0.25 seconds (assuming almost immediate device response times). I would expect these reactions times only to be achieved in practice situations, where the signal is known, clear and expected to occur imminently. However, whilst the emergency stop operators were alert and watching for an event, the incident involved an unusual, low probability event that was likely to require longer mental processing to detect and understand, requiring an urgent, emergency response and, therefore in my opinion, simple reaction times are unlikely to be achieved.

It is my opinion that, in the circumstances of this incident, the total response times that are likely to be achieved would be closest to the range suggested by studies into brake reaction times to surprise, urgent signals which are 0.76 – 1.91 seconds (including 0.2 seconds assumed delay for the door to stop moving following an emergency stop activation).

4.2 THE EFFECT THAT AN UNEXPECTED, EMERGENCY EVENT COULD HAVE ON REACTIONS TIMES

The evidence from the literature suggests that critical events requiring an emergency response where there is perceived risk of injury to self or others, are likely to generate faster reaction times than expected, anticipated, non-critical events. However, in the circumstances of the incident, in my opinion, the time taken to detect the unexpected movement of the IP (back towards the door rather than away from it) and then to understand what is happening, may not be offset by a faster reaction time for an urgent, critical event.

4.3 EFFECT ON REACTION TIMES OF PRACTICE / TRAINING

Whilst comparison of brake reaction times for unexpected but common signals with the fastest reaction times to unexpected and unusual events supports the view that practice decreases reaction times to some extent, the evidence suggests that the urgency or criticality of the event can have a greater effect in decreasing reaction times than being familiar and practised with the event. Comparison of the movement times achieved in pressing an emergency stop button for two of the industrial robot studies suggests that practicing detecting the signal and hitting the emergency button does not appear to decrease the movement time. In my opinion, practice or training in activating the emergency stop button would be unlikely to decrease the reaction times significantly in the circumstances of the incident.

4.4 SUMMARY

It is my opinion that, in the circumstances of this incident, i.e. reaction to an unexpected, low probability but critical event, the total response times that I would expect would be in the range of 0.76-1.91 seconds (including 0.2 seconds for the door to stop moving following emergency stop activation). Assuming that the door takes 1.6 seconds to close fully, I estimate that the door could be 75-100% closed within this range of reaction times. My understanding is that either the supervisor or the operator activated an emergency stop button and the door stopped with the bottom edge approximately 178-203 mm from the tunnel floor. Assuming a door height of 2 m, I estimate that the door was approximately 90% closed when it was stopped at the time of the incident. This is in line with my estimation of door closure based on the reaction times found for surprise, urgent events.

The estimates of total response times (including the door response time) in this incident suggest that, even taking the fastest human reaction times (simple reaction times) found in the literature, the door could have closed by more than a quarter of its closing distance, to a vertical height from the floor of 1500 mm, before the door could be stopped assuming a closing time of 1.6 seconds. This suggests that more than 98.5% of the UK adult population would be tall enough to be struck on the head by the door edge closing at this speed if they were in its pathway, before the door could be stopped by activating an emergency stop button. Therefore, it is my opinion that human emergency stop operation would not be a suitable control measure on its own to reduce the risk of people working in the vicinity of the door coming into accidental contact with the door if it closes in 1.6 seconds or faster.

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6 APPENDIX

6.1 LITERATURE SEARCH

6.1.1 Search terms

The keywords listed in Table 5 below were supplied to HSE's Information Centre with a request for them to carry out a search for literature relevant to a review of human reactions times in response to an emergency situation. I requested that the search considered literature, especially reviews, meta-analyses, on this subject in relevant peer-reviewed research published worldwide in scientific journals. I requested that databases covering ergonomics, human factors, safety (especially transport safety) and psychology were searched. Due to the tight timescale to carry out this review I requested that only English language articles were considered in the search. As my initial search of the literature on human reaction times indicated that much of the literature on this subject was published as far back as the 1950s, I did not ask that older literature was excluded from the search.

Table 5 Keywords used in literature search of human reaction times

Reaction time terms		*Relating to*
Reaction time(s)	AND	Driver /Driving
Response time(s)		Brake / Braking
Performance time(s)		Emergency stop
Simple reaction time		Emergency situation
Speed of reaction		Human alarm handling
Speed of performance		
Perception-reaction time		

6.1.2 Results of literature search

The literature search found 73 results in total and the following databases were searched: Ergonomics Abstracts, OshUpdate, Web of Science, Health and Safety Science Abstracts, Risk Abstracts, PsycInfo, and Transport Research International.

From these results, the abstracts were reviewed and 52 full articles requested which appeared from the abstracts to be relevant to the issue. I reviewed these full articles and excluded those that were not relevant to fast reaction times and simple (single choice) decision reactions. Twenty articles were considered as relevant to human reaction times in emergency situations. The relevant information was extracted from these articles and collated in a structured way in a Data Extraction Sheet to facilitate analysis.

6.2 SUMMARY OF RESULTS

6.2.1 Simple reaction times

Table 6 Summary of simple reaction times

Study	*Signal/ response*	*Conditions*	*Results - Mean (sec)*
Gottsdanker et al (1963)	Light /Hand movement – lever up	Expected & warning	0.25
Swink (1966)	Light /Hand movement	Expected	0.24
Swink (1966)	Siren /Hand movement	Expected	0.22
Warrick et al (1965)	Buzzing tone /Hand movement (press button)	Expected	0.2

Study	*Signal/ response*	*Conditions*	*Results - Mean (sec)*
Warrick et al (1965)	Buzzing tone /Hand movement (press button)	Unexpected & unusual	0.6
Los et al (2013)	Symbol of computer screen /Hand movement (press key on keyboard)	Expected	0.248
Salvendy et al (1997) (Textbook)	Visual /Hand movement	Expected	0.18
Grandjean & Kroemer (1997)	Various / Various - practised	Expected	0.15 (minimum)

6.2.2 Brake reaction times for expected signals

Table 7 Summary of brake reaction times for expected signals

Study /type	*Signal /response*	*Conditions*	*Results (secs)*
Norman (1952) /Road	Traffic light /Brake pedal	Expected	Mean 0.73 (95^{th} %tile 0.89)
Olson & Sivak, 1986 /Road	Red light on front of test vehicle /Brake pedal	Expected	Mean 0.6 Range 0.35 – 1.0
Summala et al 1998 /Simulator	Brake lights leading car /Brake (foot already on pedal)	Expected	Mean 0.7
Johansson & Rumar 1971 /Road	Auditory (klaxon) /Brake pedal	Expected	Median 0.66 0.9 or longer in 50% of all sudden accident scenarios
Green (2000) – review of simulator studies	Light at predetermined location /Brake pedal	Expected (low spatial & temporal uncertainty and low cognitive load	Range 0.4 -0.5
Green (2000) – review of studies	Various /Brake pedal	Expected – expecting signal to brake	Many studies agree a mean brake reaction time of about 0.70-0.75 s. Movement time is around 0.2 of this (Range 0.13-0.3)

6.2.3 Brake reaction times for unexpected but common signals

Table 8 Summary of brake reaction times for unexpected but common signals

Study /type	*Signal /response*	*Conditions*	*Results (secs)*
Broen & Chiang, (1996) /Simulator	Obstacle in road /Brake pedal	Unexpected	Mean 1.33 (sd 0.27)
Isler & Starkey (2010) /Simulator	Abrupt braking of lead vehicle with Sudden Brake Warning System (video simulation) /Press mouse button (finger already on button)	Unexpected & abrupt (night conditions):	Mean 0.83 (sd 0.32)
Schweitzer et al (1995) /Road	Braking by lead vehicle /Brake pedal	Unexpected but common	Mean 0.678
Young Sohn & Stepleman, (1998) /Meta-analysis	Brake lights, red light, object in road /Brake pedal	Unexpected	85th %tile – 1.29 – 1.52
Green (2000) review of studies /Road	Traffic lights or brake lights /Brake pedal	Unexpected – common but uncertain signal	Range 1.14 – 1.4

6.2.4 Brake reaction times for surprise, unusual signals

Table 9 Summary of brake reaction times for surprise, unusual signals

Study /type	*Signal /response*	*Conditions*	*Results (secs)*
Olsen & Sivak (1986) /Road	Obstacle – yellow foam to left of vehicle path /Brake pedal	Surprise	Mean 1.1, Range 0.8 – 1.8, 95th %tile – 1.6
Lerner (1993) /Road	Obstacle (barrel rolled into path) /Brake pedal	Surprise	Mean 1.5 (sd 0.4) Range 1.22 – 1.65 85th %tile 1.9
Ruscio et al (2015) /Road	Foam rubber cube tossed into road /Brake pedal	Surprise	Mean 1.18 (sd 0.22)
Summala (2000) /Road	Police with stop sign – obscured until last minute /Brake	Surprise – urgent (short time to collision)	Mean range 0.86 - 1.39 (estimate from model)
Dingus et al (1998) /Road	Barrel fired into path without warning /Brake pedal	Surprise	Fastest reaction time 0.65
Green (2000) review of studies /Simulator	Obstacle /Call out when saw object	Surprise intrusion	Range 1.02 – 1.33
Green (2000) review of studies /Road	Vehicle cut across, barrel rolled into road, object in road, Police holding stop sign /Brake pedal	Surprise – low probability, unusual signal	Mean 1.5 Range 1.1 – 1.8
Dozza (2013) /Analysis of crash/near-miss driving data	Crash or near-miss /Brake pedal	Surprise	Car drivers – Mean 1.45 (sd 1.07) Attentive – 1.30 Distracted – 1.55

6.2.5 Reaction times for emergency stop operation for industrial robots

Table 10 Summary of reaction times to press an emergency stop button to stop an industrial robot

Study	*Signal /response*	*Results (secs)*
Etherton & Sneckenberger (1990) Evaluated speed and contrast of robot arm on reaction time to emergency button	Unexpected movement of robot (overrun but timing uncertain). / Button held in palm of hand. Pressed when overrun movement detected (Practised using button before)	At 450 mm/s mean reaction time - 0.342 (sd 0.073) At 350 mm/s mean reaction time – 0.398 (sd 0.089) At 250 mm/s mean reaction time 0.418 (sd 0.086) At higher speeds – people less reluctant to hit emergency button and reactions more reflexive.
Collins (1989) Evaluated movement time for different emergency stop button diameters and locations.	Unexpected but random malfunction of robot arm / Time to reach emergency stop button. Three fingers to depress and hold touch pad on pendant. Release and depress emergency button. (Not practised or experienced in estop use)	For 25 mm diameter button on handheld control pendant: Fastest mean movement time 0.11. Slowest mean movement time 0.163
Kwon (1996) Effects of location and size of emergency stop button on movement time	Unexpected but timing uncertain Errors in movement of robot arm /Asked to push button on pendant when recognised errors in robot movement. Index finger next to button. (Practised using emergency stop 20 times before)	For a 38 mm diameter button: Mean movement time – 0.14 Ranged 0.13 – 0.2