Inclusive Kerbs Study

Phase 4

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Phase 4

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Glossary

Controlled crossings	Crossings with traffic signals which stop oncoming traffic to allow a period of time for crossing the road.
Delineation	The act of showing the exact position of a border or boundary.
DMRB	Design Manual for Roads and Bridges.
Drop kerb	Kerbs that are lowered at a road crossing or access to a property.
Flush	Two surfaces adjacent to each other and at the same level.
Framework	The supporting structure for the system.
Functionally Impaired / Functional Impairment	A person (or people) who have a level of difficulty in completing daily living tasks and activities
Gradient	The degree/steepness of a slope.
Long fall / Longitudinal	The gradient along the length of a surface.
NASA TLX	National Aeronautics and Space Administration (NASA) Task Load Index (TLX) – a system of measuring the workload of a particular task using a qualitative numerical grading system.
Methodology	The method used to gather information in a study or activity.
Physical	Physical (with an uppercase P) refers to the group of volunteer participants who have physical impairments.
Qualitative	A study method which uses metrics which are difficult to measure or quantify e.g., information or feedback.
Quantitative	A study method which uses metrics which can be measured and quantified, e.g., survey data or population statistics.
SRRB	Scottish Road Research Board
Third wheel	A metal bar with a wheel, attached to a wheelchair and extended to the front to assist wheelchair users,

	enabling them to raise the chair so the smaller front wheels reach the kerb, assisting the crossing.
Uncontrolled crossings	Road crossing points with no form of traffic control associated with them e.g., dropped kerbs and pedestrian islands, dropped kerbs only or a general road without any pedestrian facilities
Upstand	The portion of the kerb that is raised above the carriageway
Vision	Vision (with an uppercase V) refers to the group of volunteer participants who have vision impairments.
Perceived workload	How much work or effort is required to complete a task. Measured using the NASA Task Load Index (NASA TLX) which measures perceived workload across six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration. A subjective assessment that records perceived workload to evaluate the effectiveness of tasks or systems.

Executive summary

Scope and Purpose

The Inclusive Kerbs Phase 4 research project gathered data using a representative example of standard kerbs within a controlled laboratory environment to understand how people with various impairments interacted with them. The study was conducted by Mott MacDonald and Edinburgh Napier University's Transport Research Institute. It was commissioned by Transport Scotland on behalf of the Scottish Road Research Board (SRRB) and the Department for Transport (DfT). The Phase 4 research is part of the wider Inclusive Kerbs Study, made up of four phases of research.

Phase 1 of the project looked at existing research and found that there are few studies on inclusive kerbs that consider both engineering and human factors.

Phase 2 gathered data on in-situ kerbs and trialled online interview methods to learn more about how people use kerbs. The study considered how kerbs are used for navigating along a street and for crossing the street.

Phase 3 collected data from eleven people with moderate to severe impairments using further online interviews and site visits with volunteer participants. The information gathered from the interviews and from recordings of the participants' progress at the three visited kerb sites was compared against the online interviews and Phase 2 site surveys to identify patterns in experience.

Phase 4, reported here, trialled in controlled conditions the interaction of fifteen volunteer participants against selected kerb types and upstand heights considered to be most representative of those found in standards.

This study is intended to enhance comprehension regarding the impact of kerb design and usage on mobility, providing substantial evidence for robust kerb design; a domain that has been comparatively underexplored. The study does not seek to change current standards or guidance around the provision or design of dropped kerbs or crossing points (controlled or uncontrolled).

The findings will contribute to evidence-backed standards development, not only in Scotland, but also in the broader UK and beyond relating to kerb upstands.

Methodology

In Phase 4 a laboratory experiment used an adjustable height platformed system with interchangeable kerbs. The experiment used controlled conditions and a safe environment to gather qualitative and quantitative information from volunteer participants with a range of impairment conditions across five study groups:

- Low Vision capability group (e.g. Cane and Guide-dog),
- Moderate Vision capability group (e.g. Retinal and Macular Degeneration),
- Low Physical capability group (e.g. Wheelchair),
- Moderate Physical capability group (e.g. Walking stick), and
- Baseline (Normative) control group (no physical or vision related impairment).

Participants were asked to find and traverse four selected kerb profiles at different upstand heights between 20mm and 100mm (depending upon the kerb profile). They were asked to describe their thoughts before, during, and after the process. After traversing a kerb, they were asked to score the perceived workload (or effort required) of completing the movement using NASA Task Load Index (TLX) which is a subjective assessment tool widely used in Human Factors and Ergonomic research.

The objectives of the Phase 4 trial were to attempt to validate the previous phases of the study under controlled conditions and add robust quantitative data to the qualitative findings of previous phases. Further, Phase 4 sought to define a range of kerb upstand heights which would prove equal to all users, if possible.

To correlate the quantitative data with the qualitative information found in the previous phases additional qualitative data was also collected. Qualitative recordings of each participant’s experience as well as their responses to requests for commentary were taken and transcribed at key points during the contact between participants and the kerbs.

Findings

The principal findings from both the quantitative and qualitative data are:

- Perceived workload ratings were predominantly a combination of physical and mental effort. The amount of mental effort reported increased with reported physical effort.
- The 20mm - 25mm kerbs were detected and traversed easily by the Low and Moderate Physical capability participants. There was no preference for any of the kerb types with workload scores similar across all types.
- The 20mm - 25mm kerbs were detectable by the Low and Moderate Vision capability group participants, but with more difficulty than higher upstands. Occasionally they were not noticed by guide dogs when the participant was stepping down off a kerb.
- The 50mm – 60mm kerbs were not traversable by wheelchair users without the use of a third wheel attached to the chair or additional assistance.

- The 50mm kerbs were detectable and preferred by Low and Moderate Vision participants. Although there was a preference for the Half-Batter and Bull-Nose vertical faces over the Full-Batter.
- The 60mm kerbs were found by the Low Vision participants to require the lowest workload. However, combining workload scores from both Low Vision and Moderate Vision groups, the 50mm kerbs were preferred by visually impaired participants overall.
- The 100mm kerbs were considered hard and frustrating by all user groups, even the baseline group.
- The statistical findings were fully consistent with the pattern of results.

Conclusions

This report does not set recommendations for statutory bodies but presents information and conclusions which can be used by them to determine the future guidance.

It was concluded that these laboratory findings were consistent with the findings of the previous three phases of the project. The findings from the Phase 3 field work demonstrated a clear division between visually impaired users and physically impaired users in their response to kerbs.

Taking all groups into account it was calculated that the equitable kerb upstand height for both user groups was likely in the range between 40mm and 50mm for all kerb profiles.

Detailed conclusions for perceived workload showed some variability in workload based on kerb profile and the specific functional impairment but with overall trends remaining similar across kerb profiles.

There are several clear indicators towards possible further areas for research and evidence gathering, which could further inform standards and guidance.

1 Introduction

1.1 General

This report documents the process and findings of the Inclusive Kerbs Phase 4 research project. The project was commissioned by Transport Scotland on behalf of the Scottish Roads Research Board (SRRB) and the Department for Transport (DfT) and was conducted by Mott MacDonald and Edinburgh Napier University’s Transport Research Institute. The Phase 4 research is part of the wider Inclusive Kerbs Research Study, made up of four phases of research of which this is the final phase.

The study may lead to the change of existing, or development of new, guidance for Scotland, the UK, and beyond; it has therefore been designed to be as robust and rigorous as possible within project constraints, and to stand up to scrutiny and challenge. To achieve this, the project has used best practice methods in the design and implementation of this research project.

To direct the research and establish a foundation of prior knowledge Phase 1 conducted a literature review. The review evaluated relevant published academic research, and appropriate design policies, guidance and standards. Informal literature, including internet blogs, were also considered. Some seventy-six separate documents were reviewed as part of the study. Phase 1 established that kerb height was an under researched area, with only two papers identified with a clear research base and that the was no clear reason for kerb heights specified in standards or guidance.

To better serve the end user of any proposed kerb guidance, the project has a strong focus on the personal experiences of roadside users with functional impairments. Utilising the analysed population data, the project recruited a small number of interview participants from the highest impairment severity category to assist in online pilot interviews (Phase 2). This initial feedback was used to assist in the method development for the online and site-based interviews (Phase 3) and laboratory study (Phase 4).

Phase 2 surveyed a range of existing kerbs in different locations, collecting data on a range of attributes of kerb properties and its setting. The data gathered was then used in the Phase 2 online interviews and allowed limited associations to be made between experiences of kerb interactions and kerb design. These associations were then further defined during the Phase 3 study to allow more definitive conclusions to be reached with regard to the issues faced by functionally impaired users in the street. Finally, to understand the effect of kerb heights in isolation, laboratory-based testing has been conducted in this Phase 4.

This study is intended to enhance comprehension regarding the impact of kerb design and usage on mobility, providing substantial evidence for robust kerb design; a domain that has been comparatively underexplored. The findings will contribute to evidence-backed standards development, not only in Scotland, but also in the broader UK and beyond. The potential applications extend to related domains like crossings, signage, road markings, and vehicle automation, making this research a valuable asset for advancements in multiple related topics.

1.2 Scope and Objectives

Phase 1 of the study comprised of a literature review and recommended that a second phase be conducted looking at the kerb boundaries between footways and carriageways, footways and cycle tracks, and cycle tracks and carriageways.

Phase 2 of the study examined the interfaces identified in Phase 1 and how users interacted with them. It gathered necessary data, from online interviews with functionally impaired volunteers using a trial methodology to form a basis for recommending future studies on inclusive road design. The interviews considered the whole setting and use of the kerb for navigation, both parallel along a street, and as a point of uncontrolled crossing.

Phase 3 of the study extended to the collection of data from people with a range of capabilities, including severe to moderate and mild impairments (Langdon and Thimbleby, 2010). This was done through site-based interviews with functionally impaired volunteer participants using three of the sites identified as most appropriate from Phase 2 of the study. Data was gathered using on-site, concurrent verbal protocols, and interviews. It was compared and analysed using conventional qualitative research techniques (Neville Stanton, 2021) (J Goodman-Deane, 2010) (Flick, 2018) to identify key themes and patterns arising from the participants' experiences. This data was then analysed in order to form conclusions on existing contextual kerb conditions and the relative difficulties encountered. The conclusions were used to form a realistic baseline and provide further clarifications on the design and methodology for experimental laboratory research in Phase 4 to identify potentially suitable kerb height ranges.

The aim of the Phase 4 research is to establish quantified evidence for the difficulties posed by the kerb and, if possible, define a range of kerb upstand heights which would prove equal to all users. The Phase 4 research sought to validate the previous phases of the study under controlled conditions which allow determined parameters (e.g. height, kerb profile) to be varied. Therefore, tests were conducted on kerb interactions within laboratory conditions.

This report does not look to set recommendations for statutory bodies but to present information and conclusions which can be used to determine the future guidance.

1.3 Methodology

The laboratory trials were conducted at Edinburgh Napier Universality laboratories in a bright, clean, calm, warm, and dry environment. In so far as reasonably practicable the research team attempted to hold all other test variables constant.

The study involved the construction of a modular, variable height, articulated platform (the rig) located within the controlled indoor facility, that allowed participants to carry out the protocols securely. The rig consisted of a pair of modular platforms on jacks which could be raised or lowered independently of each other. The selected kerb was held securely in a cradle at the centre of the rig. The surface of each platform was covered in an asphaltic material to approximately match the colour of footways. The rig was accessed by a ramp and a surrounding wooden railing prevented falls from the sides. Section 2.5 further describes the set-up of the laboratory equipment including an image for reference.

The trials focused on understanding the workload or effort imposed by each kerb design, which might render the action difficult, frightening, painful, or even impossible for individuals. The NASA TLX workload questionnaire was used to gauge the perceived workload or effort required to detect and cross the kerb. This is a paper questionnaire widely used in Human Factors and Ergonomic research. It has been validated and tested for reliability in countless experiments worldwide since 1986 (Hart, 1988; Grier, 2015; Hart, 2006). Section 2.4 further describes the questionnaire in detail and how it was used.

Participants were interviewed about their lived experience of their interaction with kerbs and then invited onto the rig. On the rig they were asked to find and then cross the trial kerb, both up and down, while describing the experience to a member of the research team to record. They then left the rig and were asked to give numerical scores against each NASA TLX subscale. Meanwhile the experiment was changed onto another setting. Participants experienced kerb profiles in a different order to each other over several sessions. Cameras were held by the research team and attached to the rig to record the activity of the participants.

The project assessed four kerb profile types and five different heights. To fit within project constraints not all variations were assessed, with some not viable. In total fourteen different kerb heights and profile combinations were assessed.

The laboratory trials described in this report are the final part of the methodology of the holistic four Phase study. They are intended to validate and inform the self-reported findings from the previous interviews and site trials by use of tests in controlled conditions.

The project methodology is explained in greater detail throughout the report with specific focus in Section 2 - Methodology.

1.4 Report Structure

This report is structured to first provide the reader with the methodology used during this phase of the study as well as the background of how this method was developed and the intended outcomes. Followed by the details of, and the data gathered from, the laboratory interviews and TLX workload scores, along with the analysis of that data. The report then collates the findings from the previous phases and discusses them in context. Finally, the report provides outline conclusions, recommendations for further work and closing remarks.

The following sections of this report are:

- Section 2 which summarises the methodology used during the Phase 4 research.
- Section 3 which provides both the quantitative and qualitative results. The quantitative results from the TLX workload scores, along with the analysis of that data, are broken down by kerb type and height. The qualitative results are also presented by each kerb profile individually, with photos of participants and quotes from their commentary.
- Section 4 which describes the analysis of the results and how they can be interpreted.
- Section 5 which discusses the results in conjunction with the key findings from the previous phases of this research project. The qualitative data from their Phase 4 comments and TLX workload quantitative data are compared against the findings from previous phases to identify any patterns in experience and inform a range of kerb heights that would be most suitable for the varying impairment types.
- Section 6 which provides a summary of the outcomes and conclusions from this phase of the study along with recommendations for further study.

2 Methodology

2.1 Introduction

This phase built upon and continued the research from the previous phases which were conducted using online interviews and on street trials. In this phase a laboratory experiment in safe controlled conditions at Edinburgh Napier University was conducted using an adjustable height platform system with interchangeable kerbs to gather qualitative and quantitative information from volunteer participants with a range of impairment conditions.

Participants with different levels of visual and/or physical impairment were asked to find and traverse four selected kerb upstand heights between 20mm and 100mm (depending upon the kerb). They were asked to describe their thoughts before, during, and after the process. After they had traversed a kerb, they were asked to score the perceived workload using the NASA Task Load Index (TLX) assessment tool.

The aim of the Phase 4 research is to establish quantified evidence for the difficulties posed by the kerb and, if possible, define a range of kerb upstand heights which would prove equal to all users. The Phase 4 research sought to validate the previous phases of the study under controlled conditions which allow determined parameters (e.g. height, kerb profile) to be varied.

2.2 Participants

An ambition of the Inclusive Kerbs Study was to represent the proportions of the Scottish population who reported difficulties in daily life at various levels of severity in the functional areas represented in the Family Resources Survey (2019-2020) as outlined in the Phase 2 report.

The Scottish population data taken from the Family Resources Survey (2019-2020), discussed in Phases 2 and 3 of the study, showed that nearly 50% of those who responded to the survey had some level of functional impairment such as, difficulty with vision, stamina, learning and memory, hearing, mental health, social and behavioural capabilities, mobility, and dexterity. The results for each functional impairment were also sub-categorised by age and gender.

However, identifying and arranging participation of the range of volunteers required to meet the exact percentages of each functional impairment which represent the population would significantly expand the scope of the study beyond the project constraints. It would also detract focus away from those who are predominantly affected by the issue of kerb upstand heights and profiles.

In Phases 2 and 3, the research team concluded that the two main categories of functional impairment which affected how people interacted with kerb heights and profiles were; mobility and dexterity (physical capability), and difficulty with vision. In the Scottish population data, 45% of those who reported a functional impairment reported difficulty with mobility and dexterity, and 10% reported difficulty with vision.

The Phase 4 research therefore focused on these two principal categories; mobility and dexterity (physical capability) and vision. Age and gender were not controlled and were recruited opportunistically based on availability of volunteers. As shown in Figure 2-1, below, the volunteer participants for Phase 4 were accepted into one of five participant groups based upon their dominant functional impairment:

- Low Vision capability group (e.g. Cane and Guide-dog),
- Moderate Vision capability group (e.g. Retinal and Macular Degeneration),
- Low Physical capability group (e.g. Wheelchair),
- Moderate Physical capability group (e.g. Walking stick), and
- Baseline (Normative) control group (no physical or vision related impairment).

Participants	Group	Age and Aid Description	Note
K1	Low Vision	70+ Cane user.	Non-complete
K2	Low Vision	25+ Assisted hearing. Guide Dog and Cane user.	Completed
K3	Low Vision	40+ Cane user.	Completed
K4	Low Vision	70+ Assisted hearing. Cane user.	Non-complete
K5	Low Physical	60+ Wheelchair user.	Completed
K6	Low Physical	40+ Wheelchair and Crutches user.	Non-complete
K7	Low Vision	74+ Very low vision.	Completed
K8	Low Physical	70+ Wheelchair user.	Completed
K9	Moderate Physical	70+ Wheelchair user.	Non-complete
K10	Low Vision	80+ Guide Dog and Cane user.	Non-complete
E1	Normative	60+ Assisted hearing.	Completed
E2	Normative	50+ Assisted hearing.	Completed
K11	Moderate Visual	60+ Cane user.	Completed
K12	Moderate Visual	18+ Cane user.	Completed
K13	Moderate Visual	35+ Cane user.	Completed
K14	Moderate Visual	65+ Cane user.	Completed
K15	Moderate Visual	18+ Cane user.	Completed
K16	Moderate Physical	45+ Stick user.	Completed
K17	Moderate Physical	65+ Stick user.	Completed
K18	Moderate Physical	40+ Stick user.	Completed

Figure 2-1: Matrix of participants

The opportunity to participate was advertised by an information release and ‘call for participation’ distributed to relevant Scottish organisations by email. Several previous participants from prior phases who had indicated their willingness to continue were also contacted.

The following list of organisations were contacted and assisted in finding volunteers for the study:

- Spinal Injuries Scotland
- Scottish Guide Dogs for the Blind
- Roads for All forum
- The Royal National Institute of Blind People (RNIB)
- The Scottish RNIB
- The Pocklington Trust
- Disability and Equality Scotland
- Lothian Council
- The Mobility and Access Committee for Scotland
- The Edinburgh Access Panel
- Health and Social Care Alliance Scotland (the ALLIANCE)
- Centre For Inclusive Living Perth & Kinross

Along with a description of what to expect and what level of commitment was required volunteers were sent an information pack with details of the purpose, funding, and stakeholders on the project. It was explained that informed consent would be required, their data management rights were explained, and that participants were informed that they could withdraw at any time and the safety and comfort provisions were outlined. A small honorarium retail voucher was offered to participants as an acknowledgement of their effort and any travel expenses were reimbursed as appropriate.

Table 2-1: Table of participants who completed the Phase 4 research

Participants who completed Phase 4		
Group	**Participants**	**%**
Low Vision	3	20%
Moderate Vision	5	33%
Low Physical	2	13%
Moderate Physical	3	20%
Baseline control	2	13%
Total	**15**	**100%**

2.3 Kerbs

Four kerb profiles were identified for assessment from the Phase 2 and Phase 3 studies. These are common kerb profiles used in engineering and streetscaping projects. These were:

- Full-Batter – kerb with a 45-degree splay
- Half-Batter – kerb with a 12.5-degree splay
- Bull-Nose – kerb with a straight 90-degree edge
- Cycle Segregation – large kerb with a 45-degree splay on one side and 12.5-degree on the other.

Previous phases of the research study indicated the different heights these profiles of kerbs were likely to be found at, and which heights and profiles caused problems for the functionally impaired community.

Within the project constraints, 14 kerb upstand heights and profile combinations were chosen from the upstands and profiles identified.

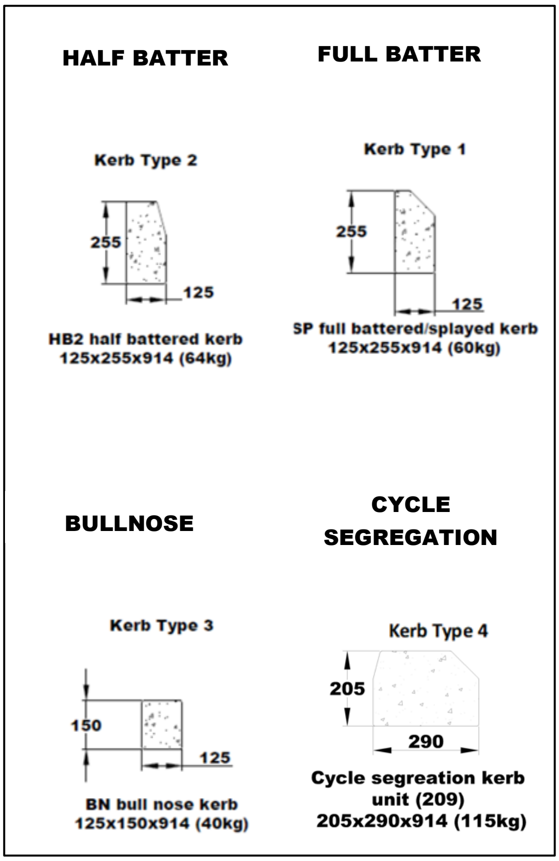

Figure 2-2: Illustration of assessed kerbs

The Half-Batter and Bull-Nose were tested at upstands of 25mm, 50mm, 60mm and 100mm. To avoid unnecessary repetitive testing the Full-Batter was not tested at 100mm, as it was already found to be difficult for all participant groups when testing the other kerb profiles.

The Cycle Segregation kerb was tested at upstands of 20mm, 25mm and 50mm. The shape of this kerb does not allow higher upstands.

The kerb elements conformed to BS EN 1340:2003 Concrete Kerb Units.

A matrix of the profiles and upstands used in the Phase 4 experiment can be found in Table 2-2, below.

Table 2-2: Matrix of conditions of kerb profile and upstand

Kerb profile	Upstand height				
	20mm	25mm	50mm	60mm	100mm
Full-Batter (SP)	-	FB-25	FB-50	FB-60	-
Half-Batter (HB2)	-	HB-25	HB-50	HB-60	HB-100
Bull-Nose (BN)	-	BN-25	BN-50	BN-60	BN-100
Cycle Segregation (CS)	CS-20	CS-25	CS-50	-	-

2.4 NASA TLX

The NASA Task Load Index (Hart, 1988) is a multi-dimensional psychological rating procedure that provides an overall workload score based on a weighted average of ratings on six sub-scales: Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort, and Frustration. These are defined in Figure 2-4: NASA TLX Rating Scale Definitions, below.

The NASA Task Load Index is a two-part evaluation procedure consisting of both weights and ratings. The first requirement is for each participant to evaluate the “weight” of each factor to the workload of a specific task. This sets how much the participant felt that factor contributed to the task. The weighting is obtained for each different task or task element upon its completion. This sheet is presented on in Figure 2-3, opposite.

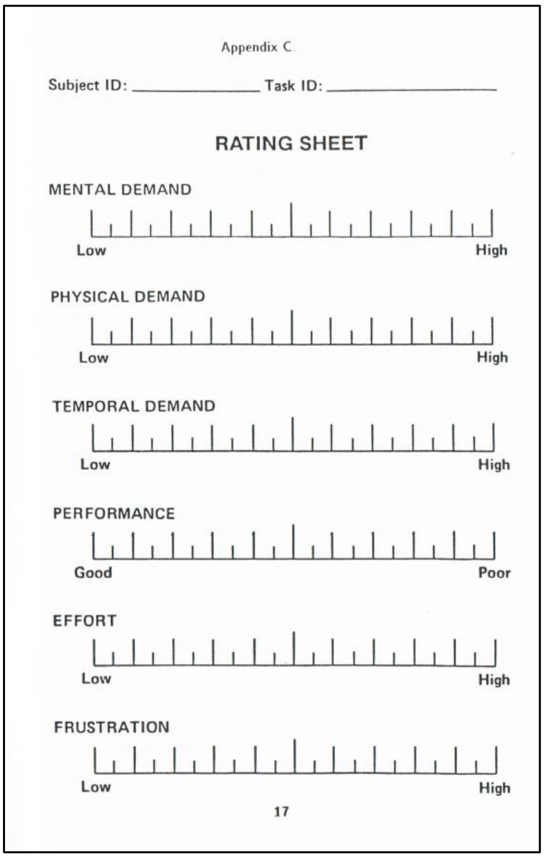

Figure 2-3: NASA TLX rating sheet (weighting)

The second requirement is to obtain numerical ratings for each factor on a scale of 0 to 100 that reflect the magnitude of that factor in a given task. Participants responses were recorded by marking each scale at the desired location. A weighted workload score is thereby calculated using the source of workloads and the rating sheets for each task.

For this experiment the numerical scores were then interpreted based on the calculated workloads and categorised as:

- Low (0-9),
- Medium (10-29),
- Intermediate (30-49),
- High (50-79), or
- Very High (80-100).

Based on the results of the weighting procedure, the TLX direct unweighted ratings can be used directly. This method is predominantly used in contemporary human factors studies (Grier, 2015; Hart 2006). The significance of the sub-scales is dependent on the nature of the task and if the unweighted scores are highly correlated, they may be used interchangeably with weighted scores. Therefore, for the purposes of this research we have used the unweighted scores. All references to the workload scores in the following sections of this report are the unweighted workload scores.

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*good/poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Figure 2-4: NASA TLX Rating Scale Definitions

2.5 Test Platform

The study required the construction of a system which would allow participants to experience different kerb upstands and profiles safely.

The test platform, ‘the rig’, consisted of two platform units abutted to each other with the ability to vary heights independently. In the centre a cradle securely held the selected kerb.

The modular nature of the rig allowed for it to be reconstructed between sessions. Maximising space saving while maintaining the capability for multiple kerb element changes.

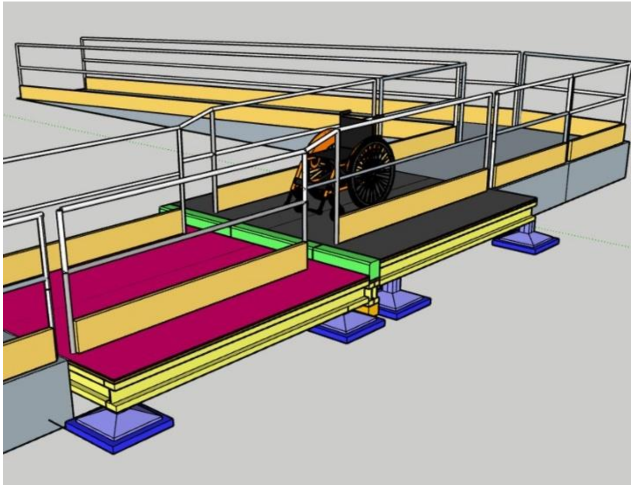

Figure 2-5. The concept design of test platforms

Access to the platforms was provided by a ramp sufficient for a wheelchair user with a less than 1:12 slope.

The unit sections were surfaced with a hard-wearing and rough, bonded grit, unreflective material in order to approximate an asphalt surface. The ramp platform dimensions were based on Building Regulations Part M to allow a wheelchair to have sufficient manoeuvrability with additional space for the experiment safety personnel to occupy the platform as well.

To create a safe environment the laboratory was cleared of hazards before each participant began each experiment. Each platform was protected with a robust wooden railing to reduce the likelihood of falls off the sides. On the platform with each participant a designated safety person was positioned to step in and provide assistance if required.

During the experimental procedure the central channel located between the two platforms (in green on Figure 2-5) allowed the positioning of standard kerb units. These were lowered into position using a gantry crane after the sections were locked together. The height differences required by the experiment were attained by adjusting the heights of the jack pads (in blue on Figure 2-5). Kerbs were fixed into the channel using a sand filler to reduce movement. Figure 2-6, below, provides an annotated photo of the test rig.

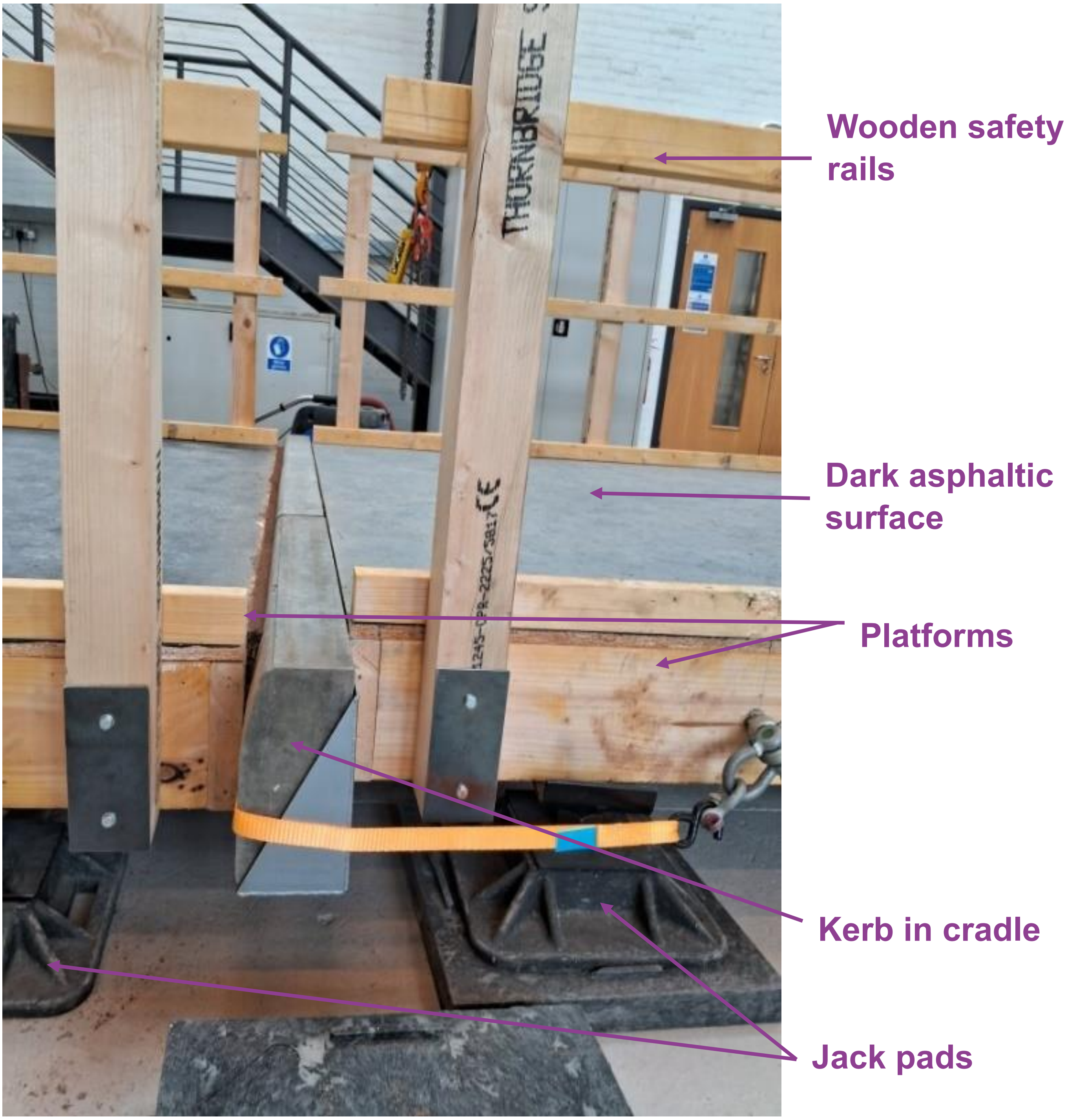

Figure 2-6: Test rig photo with annotations

2.6 Experimental Procedure

Participants were guided to the laboratory safe area and provided with a safety briefing by technicians. The researcher then explained what was to happen and how the experimental rig was configured. Participants were read the relevant consent information, including the right to stop at any time. The type and upstand height of the kerbs were not disclosed to the participants, and the order of the kerb types was non-sequential. The protocol for the participants' visit from arrival at entrance to the laboratory is given in the Daily protocol sheet in Appendix B.1.2.

There were two researchers present at all times. The first interacted with the participant and monitored them throughout the experiment. They carried a GoPro camera on a head mount to record the details of the participants traversing the kerbs and their statements in response to predefined questions. The second researcher had a safety role and was required to be near the participant at all times to provide assistance if necessary and mitigate against safety risks such as slips, trips, falls, or collisions. They were also required to ensure the participant made safe progress up and down the ramp. A second camera was mounted to an adjacent gantry and recorded all movement on and around the rig.

Each participant was escorted onto the rig using the ramp. They were rotated 90° to face the kerb and asked to cross it (going down the kerb). Their actions and comments were observed and recorded. Once across they were asked to rotate 180° to face the direction they had navigated and to cross back over the kerb (going up the kerb), thus experiencing both up and down perpendicular kerb traverses. They were also asked if they could find and track the kerb laterally, if possible. Finally, they were asked how they felt making the crossing, in both directions. This forming the basis of the qualitative notes.

After leaving the rig via the ramp they were escorted to a comfortable seating area and the researcher orally went through the NASA-TLX questionnaire, recording their responses on the paper. Participants then waited for their next kerb upstand height and profile to be set or returned on another occasion. Refreshment and lunch were supplied in a comfort room in a separate part of the building.

The procedure was based around an experimental design with two variable factors of the kerb height and kerb profile. The participants experienced all conditions, and the order of presentation of profiles and upstands was randomised.

3 Experiment Results

3.1 General

Data from the experiment was collected in two formats. The first was the quantitative scores provided by the participants on their perceived workload TLX scores. The second was the qualitative recordings of each participant's experience and their responses to requests for commentary throughout the trial. These were recorded and transcribed at key points during the contact between participants and the kerbs.

This section describes the results for the TLX scores overall and then isolates the scores for the highest scoring subscales, physical and mental workload, to show their impact on the overall scores. Each kerb profile is then presented individually, with the TLX workload scores shown graphically and the qualitative results presented with photos of participants and quotes from their commentary.

The analysis of the combined qualitative and quantitative results overall is presented in Section 4.

Section 5 discusses the results in conjunction with the key findings from the previous phases of this research project.

3.2 Task Load Index Results

3.2.1 Unweighted General Comments

Figure 3-1 below, shows the average unweighted perceived workload scores for the four kerb profiles at the upstand heights tested by each participant group. As the scores for both the Low Physical and Moderate Physical groups were similar, they have been combined into one 'Physical' group for the purpose of reporting the results. A dashed line on each profile indicates the 50 mark on the workload score, after which point it could be considered High difficulty (Table 3-1).

From the graphs, and the scores presented in

Table 3-3, it can generally be seen that for the participants in the Physical and Baseline control groups the unweighted perceived workload increases comparative to the height of the kerb for all kerb types and upstands.

Conversely, the perceived workload for the participants in the Low Vision and Moderate Vision groups were mixed. The perceived workload scores decreased as the kerb heights increased towards the 50mm or 60mm kerb upstand but the 100mm kerb height had a higher perceived workload.

The results show the common hypothesis that the Physical and Vision groups have opposing reactions to the kerb upstands as discussed in the Phase 3 report.

Table 3-2 shows that the Physical group rated 57% of the kerb types trialled as requiring either an Intermediate (43%) or High workload (14%). The High workload scores relate to the two 100mm high kerbs that were assessed. The lower kerb heights were rated as requiring the lowest workload overall by the Physical group (Low and Medium workloads).

The Low Vision group rated 57% of the kerb types as requiring an Intermediate workload with the remainder rated as Medium workload. The Moderate Vision group only rated 29% of all kerb profiles as requiring an Intermediate workload with the rest rated as Medium Workload. No kerb profiles were rated as requiring a High workload by either of the Vision groups.

Table 3-1: Perceived workload score categories

Category	Workload
Low	0-9
Medium	10-29
Intermediate	30-49
High	50-79

Table 3-2: Percentage of perceived workload scores by category and participant group

CATEGORY	PHYSICAL	LOW VISION	MODERATE VISION	BASELINE
Low	7%	0%	0%	86%
Medium	36%	43%	71%	14%
Intermediate	43%	57%	29%	0%
High	14%	0%	0%	0%

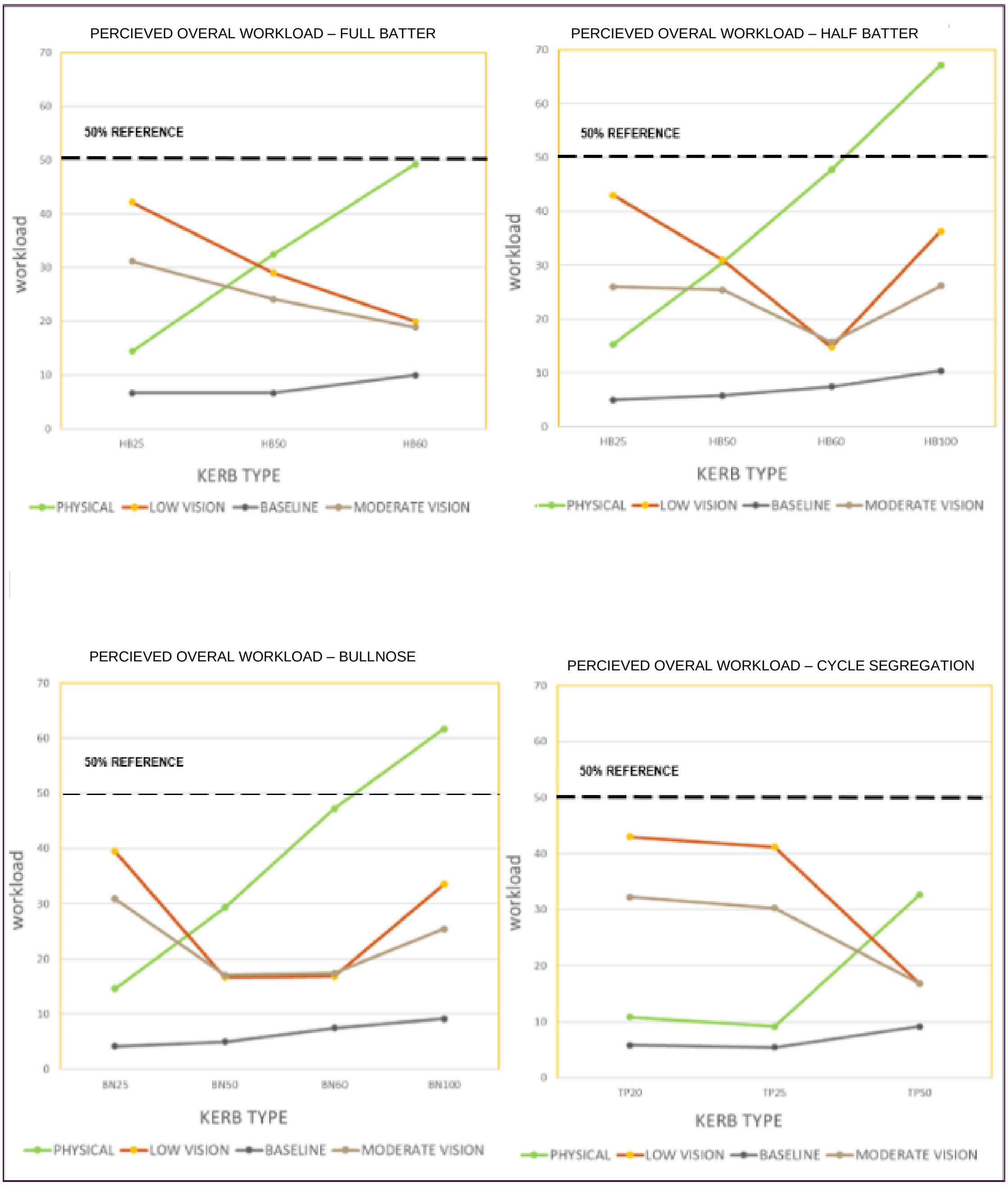

Figure 3-1: Overall perceived workload TLX rating results

Table 3-3: Unweighted overall perceived workload TLX ratings by participant group and kerb type (for colour code and category range see Table 3-1)

Kerb	PHYSICAL	LOW VISION	MODERATE VISION	BASELINE
FB25	14	42	31	7
FB50	33	29	24	7
FB60	49	20	19	10
HB25	15	43	26	5
HB50	31	31	25	6
HB60	48	15	16	8
HB100	67	36	26	10
BN25	15	40	31	4
BN50	29	17	17	5
BN60	47	17	17	8
BN100	62	34	25	9
CS20	11	43	32	6
CS25	9	41	30	5
CS50	33	17	17	9

3.2.2 Factor Isolated Results

3.2.2.1 Physical Workload Ratings

The physical workload scores on the NASA TLX assessment were the highest rated scores overall. The diagrams in Figure 3-2 shows the perceived workload scores for the physical workload subscale only.

Similar to the overall workload, the results show the increase in perceived workload as the kerb heights increase for the Physical group. For the Low and Moderate Vision groups, a similar pattern was also observed where the physical workload decreases as the kerb heights increase towards 50mm and 60mm but increases again for the 100mm kerb heights. This suggests that most of the overall perceived workload was attributed to physical workload.

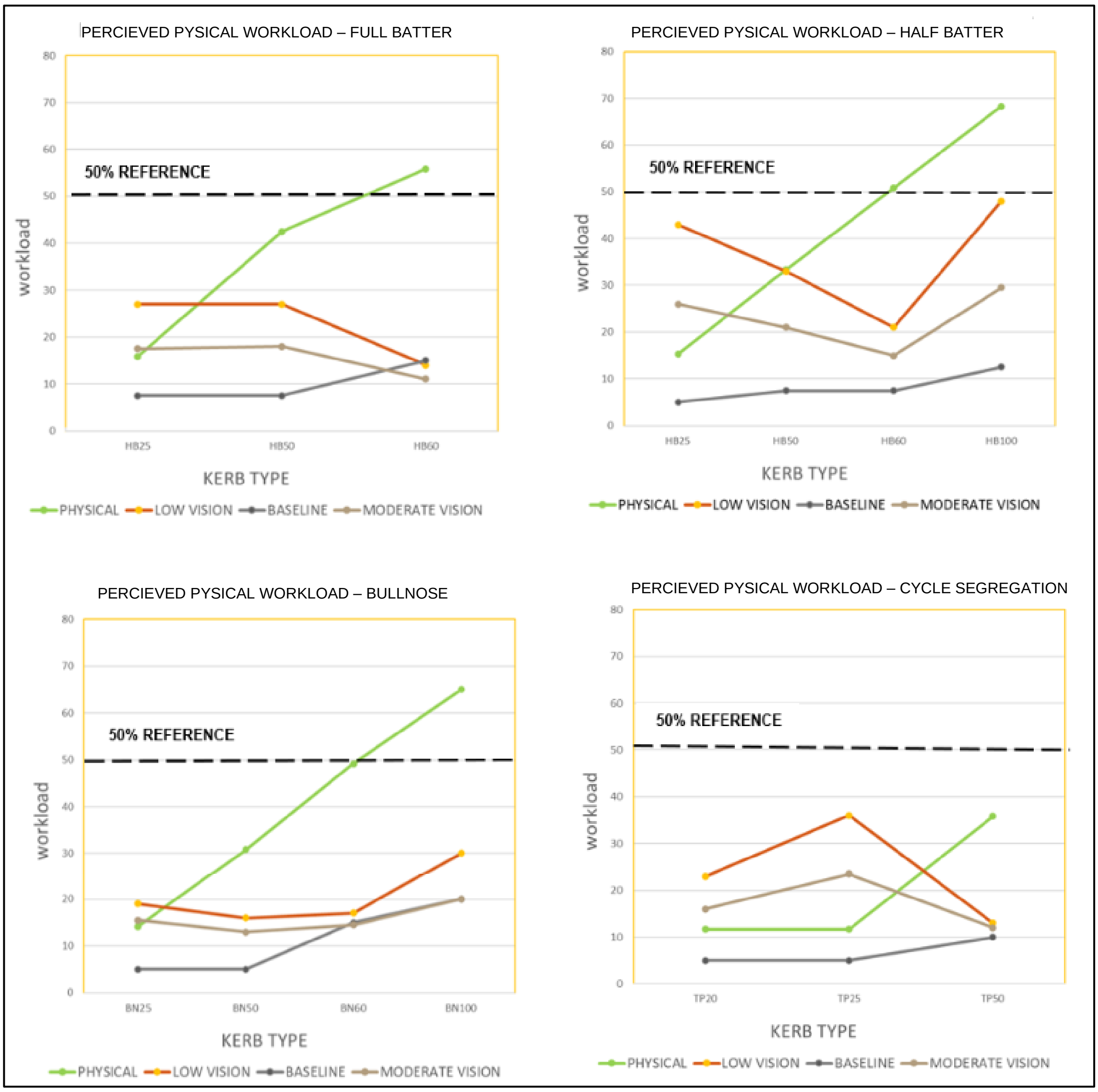

Figure 3-2: Isolated perceived physical workload TLX rating results

3.2.2.2 Mental Workload Ratings

The mental workload scores on the NASA TLX assessment were the second highest rated scores overall. The diagrams in Figure 3-3 shows the perceived workload scores for the mental workload subscale only.

For the Physical capability group, the results also show an increase in mental workload as the kerb heights increase, showing there is a connection between physical and mental workload.

For the Low and Moderate Vision groups the mental workload was higher with lower kerbs showing the effort required to detect the kerb. Most of the mental workload overall was driven by the kerb shape with the Bull-Nose kerb shape requiring less mental workload to detect.

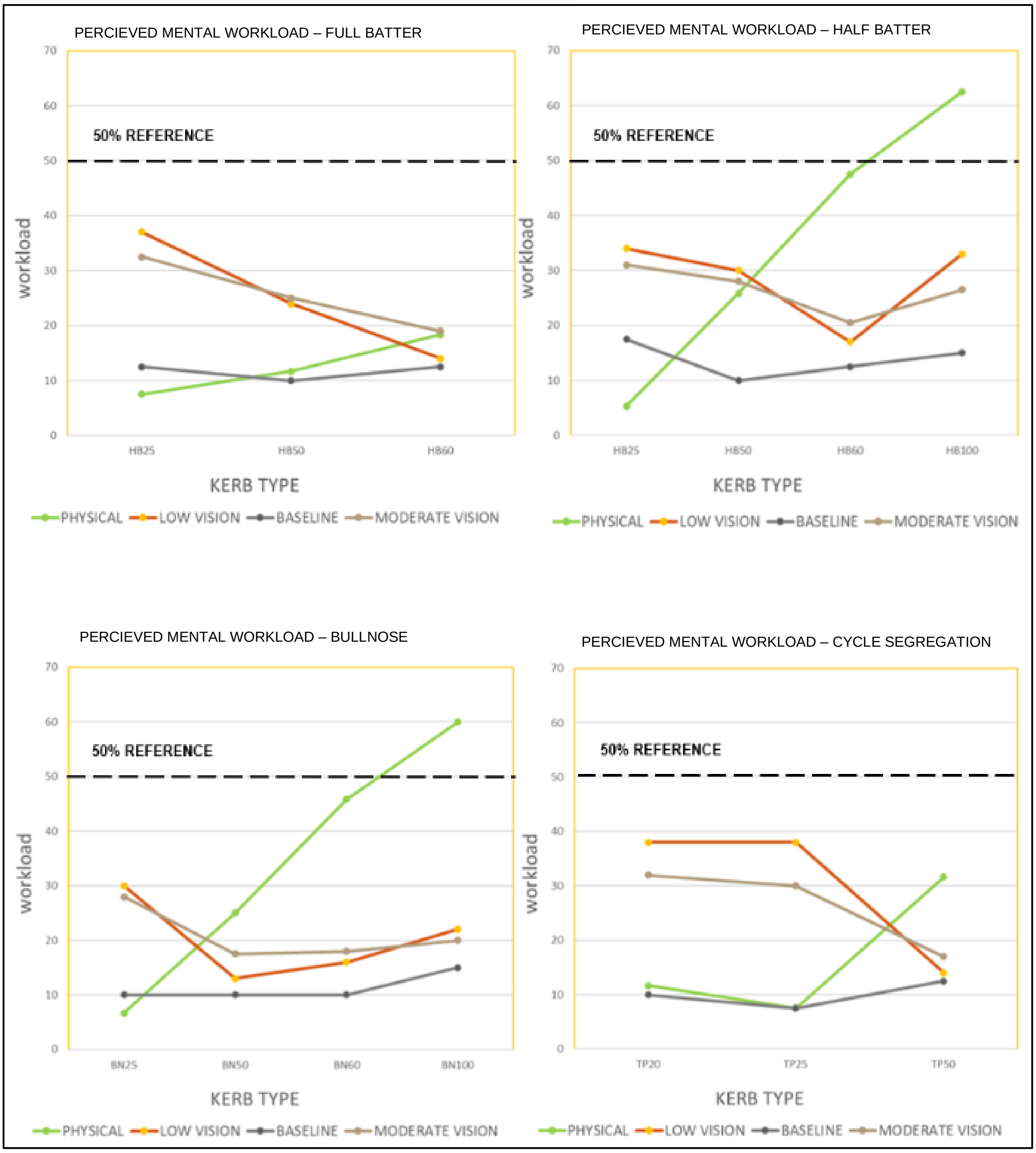

Figure 3-3: Isolated perceived mental workload TLX rating results

3.2.3 TLX Results Comments

Overall, for the Physical group both physical and mental workload increased as the kerb height increased. This reflects the increased effort required by the participants to cross the kerb as it gets higher. For the lower kerb heights overall perceived workload scores were reported below 20 (Medium workload) and increased to over 50 (High workload) for the 100mm kerbs.

Both the Low Vision and Moderate Vision groups reported higher workload scores when detecting the 20 and 25mm kerbs. All workload scores were between 30 – 43 (Intermediate workload) except for the Half-Batter 25mm kerb which the Moderate Vision group reported a lower overall workload score to detect of 26 (Medium workload). These groups included all methods of detection including, guide dog, cane, and sight. These groups reported mainly Medium workload scores for the 50mm and 60mm kerb heights, finding these the least effortful to detect. However, at the 100mm kerb heights the physical effort of crossing the kerb overtook the difficultly of detection and the workload increased for both groups.

The Physical group had a preference for the 20mm and 25mm kerb heights. All kerb types were scored very similarly at these heights with slightly lower workload scores for the Cycle Segregation kerb. They also gave similar workload scores for the 50mm and 60mm kerb heights with little difference across the different kerb heights.

The Low and Moderate Vision groups had a preference for the 50mm and 60mm kerb heights. At the 50mm height the Bull-Nose and Cycle Segregation kerb types had the lowest reported workload scores compared to the other kerb types. At the 60mm height these groups reported lower workload scores for the Half-Batter kerb compared to the other kerb types.

The majority of results from all groups were in the Medium (10 – 29) and Intermediate (30 – 49) workload categories.

The results have been isolated for physical and mental workload as they were the two prevalent factors in this experiment. The physical workload scores appear to have a higher effect upon the overall workload scores which suggests that this is the main factor influencing overall workload and effort.

3.3 Full-Batter Kerb

3.3.1 General

A standard Full-Batter Kerb is 255m tall by 125mm in either solid stone or concrete with a 45-degrees splay, as show in Figure 3-4. The full height of the kerb is not used as the upstand, only the exposed top 25mm – 60mm. The remaining height is beneath the surface and does not influence the experience of traversing the kerb.

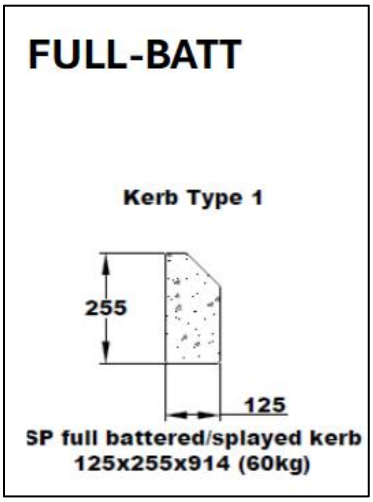

Figure 3-4: Full-Batter kerb standard dimensions

3.3.2 TLX Results

From Figure 3-5 and Table 3-4 it can be seen that the Physical group found the increasing kerb upstand height difficult, with overall perceived workload scores raising from 14 (Medium) to 49 (Intermediate). The 100mm kerb height was not assessed for this kerb profile as it was already scored as requiring a high workload for the other kerb profiles.

In contrast the Low Vision group (cane and guide-dog) found the increasing kerb upstand height easier to detect, decreasing their overall workload from 42 to 20 as the kerb upstand increased.

The Moderate Vision capability group (retinal and macular degeneration) also found the increasing kerb height easier to detect and reported a lower workload than the Low Vision group, decreasing from 31 to 19 as the kerb heights increased from 25mm to 60mm.

The baseline control group reported low workload scores for the 25mm and 50mm kerb heights with a slight increase in workload for the 60mm upstand.

Table 3-4: Full-Batter kerb profile overall perceived workload TLX ratings

Kerb	PHYSICAL	LOW VISION	MODERATE VISION	BASELINE
FB25	14	42	31	7
FB50	33	29	24	7
FB60	49	20	19	10

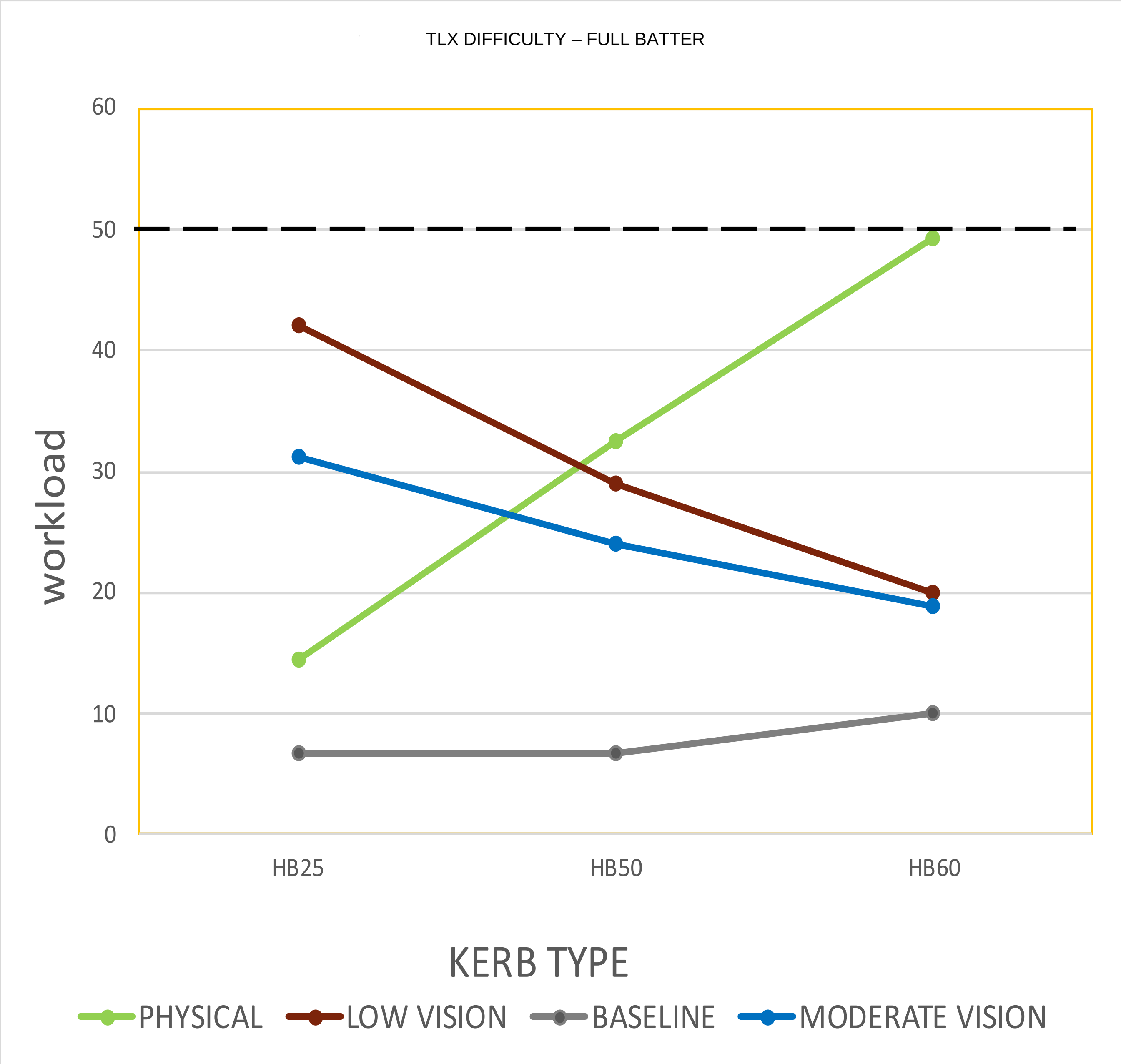

Figure 3-5: Full-Batter kerb overall perceived workload TLX rating results

3.3.3 Qualitative Findings

3.3.3.1 Vision Group

Participant K3 (Low Vision) noted that the Full-Batter kerb profile at the 25mm upstand was detectable with their trained guide dog.

As the upstand height increased the dog became more confident in its detection. Participant K3 noted that the 50mm upstand height was better and more detectable than the 25mm.

They also noted that the 50mm upstand was more detectable with the cane, but that the chamfered profile caused the ball to slide, reducing the ease of detection. Participant K3 stated:

> "The step is easier but what makes it harder is …see it gets caught in the gutter…"

Participant K12 (Low Vision) reported that both they and their guide dog could easily detect the 60mm kerb.

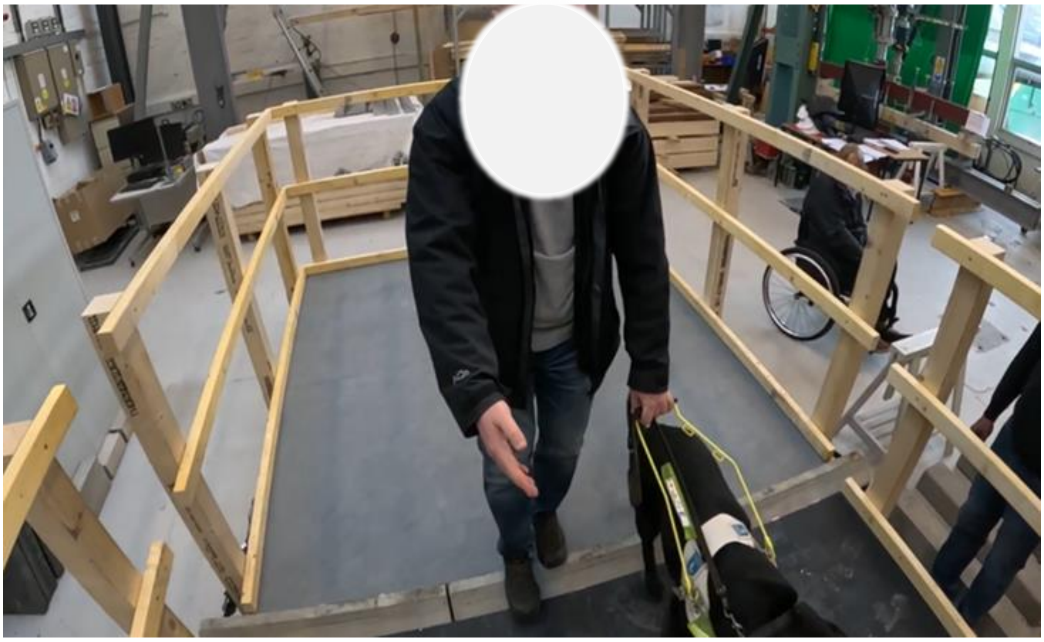

Figure 3-6: Low Vision participant with guide dog on the Full-Batter kerb

3.3.3.2 Physical Group

Participant K18 (Moderate Physical, cane) and Participant K5 (Low Physical, wheelchair) both stated that the 25mm upstand was easy for them to cross.

However, higher kerb upstand heights proved problematic. Participant K5 was unable to traverse the 50mm kerb upstand, and stated they would not attempt it on their own. They also noted that they would not attempt either the 50mm or 60mm Full-Batter kerb profile with or without the third wheel attached to their chair, even with safety staff present:

"…I wouldn't attempt it… it's too high."

Participant K3 (Low Physical, wheelchair) was also unable to traverse the 60mm upstand due to its height.

Participant K18 noted that the higher the height of this kerb, the lower the effectiveness of the slope. As such, they preferred the lower height 25mm. As the height of the kerb goes beyond a certain point the chamfer was found not to be useful for this user.

Figure 3-7: Moderate Physical participant on Full-Batter kerb

3.3.4 Analysis

Both the quantitative workload scores and qualitative statements from participants suggest that the 25mm kerb height was detectable by all participants. However, the mental workload for the Vision groups at this kerb height was higher than the mental and physical workload for the Physical group as it was harder to detect the kerb.

As the kerb height increases to 50mm and 60mm, the Physical groups reported a higher workload than the Vision groups. Both the Low and High Vision groups found it easier to find and traverse the kerb whereas the Low Physical (wheelchair) group began to have difficultly traversing the kerb, with one participant unable to traverse the kerb at either 50mm or 60mm. The Moderate Physical participants also preferred the lower kerb heights.

From the Qualitative and graphic results (above) we can conclude from this that there is evidence that for the Low Visual and Moderate Visual groups that overall workload decreased as kerb height increased.

From the Qualitative and graphic results (above) we can conclude from this that there is evidence that for the Physical group that overall workload increased linearly as the kerb height increased. For wheelchair users in particular this was primarily driven by the users perception that there was a greater potential risk that they would topple, tip or that the movement would cause significant vibration and hence pain and discomfort. However, this perception seemed to be lesser for this kerb type when compared to both the Half-Batter and Bull-Nose kerb types shown in the graphs displaying mental workload in Figure 3-3. The mental workload for Full-Batter kerbs was considerably lower than that of the Half-Batter due to the shallower slope associated with Full-Batter kerbs allowing an easier and smoother crossing than steeper kerb types.

3.4 Half-Batter Kerb

3.4.1 General

A standard Half-Battered Kerb is 255m tall by 125mm in solid stone or concrete with a 12.5-degrees splay, as show in Figure 3-8. The full height of the kerb is not used as the upstand, only the exposed top 25mm – 100mm. The remaining height is beneath the surface and does not influence the experience of traversing the kerb.

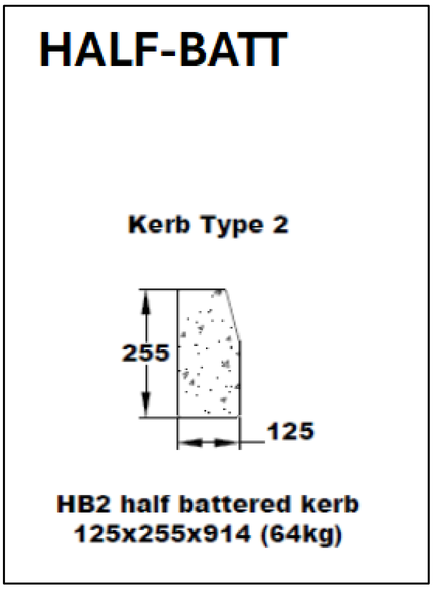

Figure 3-8: Half-Batter kerb standard dimensions

3.4.2 TLX Results

From Figure 3-9 and Table 3-5 it can be seen that the Physical group found increasing kerb upstand height difficult, with overall perceived workload scores raising from 15 (Medium) to 67 (High). Between the 60mm and 100mm kerb the workload increased 40%.

In contrast the Low Vision group (cane and guide-dog) found the increasing kerb upstand height easier to detect, decreasing their overall workload from 43 to 15 between 25mm and 60mm. However, they also experienced an increase in workload of 58% up to 36 (Intermediate) when the upstand was set at 100mm.

The Moderate Vision group (retinal and macular degeneration) did not report over a Medium workload for any of the kerb heights. They found both the 25mm and 50mm upstands required a similar level of workload to detect (Medium workload of 26 and 25 respectively). Their reported workload decreased to 16 at 60mm finding it even easier to detect. The overall reported workload also increased for the 100mm kerb, however it was a similar level to the workload experienced for the 25 and 50mm kerb heights (26 Medium workload).

The baseline control group reported low workload scores for the 25mm, 50mm and 60mm kerb heights with a slight increase in workload for the 100mm upstand.

Table 3-5: Half-Batter kerb profile overall perceived workload TLX ratings

Kerb	PHYSICAL	LOW VISION	MODERATE VISION	BASELINE
HB25	15	43	26	5
HB50	31	31	25	6
HB60	48	15	16	8
HB100	67	36	26	10

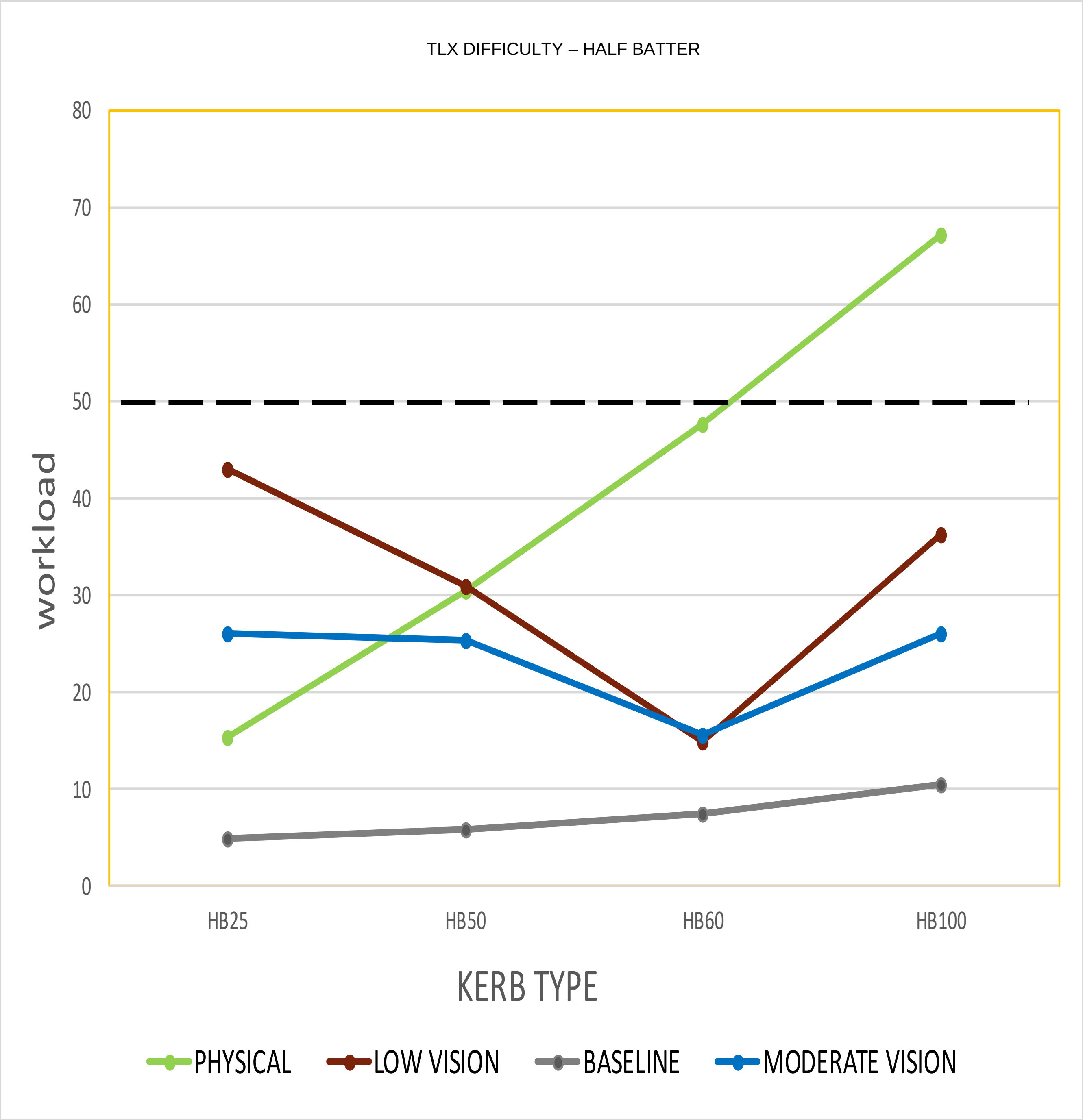

Figure 3-9: Half-Batter kerb overall perceived workload TLX rating results

3.4.3 Qualitative Findings

3.4.3.1 Vision Group

Participant K3 (Low Vision) stated both themselves and their guide dog were aware of the 25mm kerb upstand while ascending the kerb, but their guide dog was not aware of the kerb while descending:

"I'm aware of it and she's aware of it when stepping up but stepping down I don't think she saw it. I did because I could feel it. It's easier to feel stepping up than stepping down."

Both the participant and the guide dog were aware of the kerb for upstands of 50mm and above in both directions.

Participant K3 also noted that the 25mm kerb upstand was much easier to detect with the cane than with the guide dog. Their awareness of the kerb was more pronounced with the cane, stating:

"with [their dog] I felt the kerb more but with cane stepping down is easier to feel"

Participant K12 (Moderate Vision, cane) found the 25mm kerb height easy to detect with their cane:

"… for me, personally, the height is good. I think the cane will catch it and its good"

Participant K3 also thought the 50mm was easily detectable, but the edge of the kerb was too smooth and may be more difficult to detect without a cane:

"The step height is good – easy to use - but with stick interestingly - the material is very smooth - but I do feel it - in the real world it's very smooth…"

Figure 3-10: Low Vision participant on Half-Batter kerb with cane

3.4.3.2 Physical Group

Participant K18 (Moderate Physical, cane), stated that they preferred the upstand height of 25mm.

Participant K5 (Low Physical, wheelchair) was not able to ascend or descend the Half-Batter kerb profile at 50mm upstand without the extended third wheel attached to their chair. Participant K5 states that:

“at 50mm height without the extended third wheel that [I feel that] I will fall over.”

"That’s fine with my wheel on”

“If I was on my own, I wouldn’t try – frightened that I would fall over- you need to come at it at speed - it makes me very nervous – it’s a confidence thing …”

Participant K5 was not able to traverse the 100mm kerb. They noted that 100mm was too high and can be frustrating, especially in residential areas due to the lack of controlled crossings.

Participant E2 (Baseline, hearing) noted that 100mm was slightly too high to traverse comfortably. This is due to the perceived increase in workload to cross this kerb in both the upward and downward directions.

Figure 3-11: Low Physical participant in wheelchair on Half-Batter kerb

3.4.4 Analysis

Both the quantitative workload scores and qualitative statements from participants suggest that the 25mm kerb height was detectable by all participants. However, the mental workload for the Vision groups at this kerb height was higher than the mental and physical workload for the Physical group as it was harder to detect the kerb.

However, for this kerb profile, the guide dog was not aware of the kerb whilst descending off the kerb. In addition, it was noted it was much easier to detect the kerb at this height using the cane than with the guide dog.

As the kerb height increases to 50mm and 60mm, the Physical groups reported a higher workload than the Vision groups. The Vision groups found it easier to find and traverse the higher kerb heights whereas the Low Physical group (wheelchair) had difficulty traversing the kerb and required the third wheel to be fitted to their wheelchair. Even with the third wheel attached one participant was still unable to traverse the kerb.

In contrast, the Vision groups felt the 50mm kerb was a good height for them, although one participant noted the kerb was too smooth and may be difficult for a cane user to detect.

The Moderate Physical group (cane) considered 50mm a natural height for a kerb.

For all participants, including the baseline, the 100mm kerb was considered to be an undesirable increase in workload, taking it universally above a Medium score. The Half-Batter 100mm kerb type had the highest workload score for the

Physical group across all kerb types tested. This kerb profile also scored slightly higher than the 100mm Bull-Nose kerb across all participant groups.

From the Qualitative and graphic results (above) we can conclude from this that there is evidence that for the Low Visual and Moderate Visual groups that overall workload decreased as kerb height increased up to a certain point where the workload again increased as the workload went from being about detecting the kerb to the physical effort of actually crossing it. For visually impaired participants the perceived workload varied dependant on the participants visual aid or capability i.e. cane, guide dog, or visual capability.

From the Qualitative and graphic results (above) we can conclude from this that there is evidence that for the Physical group that overall perceived workload increased linearly as the kerb height increased. However, it should be noted that the increase in workload was more pronounced for the Half-Batter kerb type compared to the Full-Batter. For wheelchair users in particular this was primarily driven by the users perception that there was a greater potential risk that they would topple, tip or that the movement would cause significant vibration and hence pain and discomfort. This corresponds to the data shown for mental workload in Figure 3-3 for Half-Batter kerbs which is considerably higher than that of Full-Batter kerbs due to the steeper slope associated with Half-Batter kerbs preventing an easier and smoother crossing than shallower kerb types.

3.5 Bull-Nose Kerb

3.5.1 General

A standard Bull-Nose Kerb is a 150mm tall by 125mm wide solid stone or concrete block with a straight edge and no splay, as show in Figure 3-13. The full height of the kerb is not used as the upstand, only the exposed top 25mm – 100mm. The remaining height is beneath the surface and does not influence the experience of traversing the kerb.

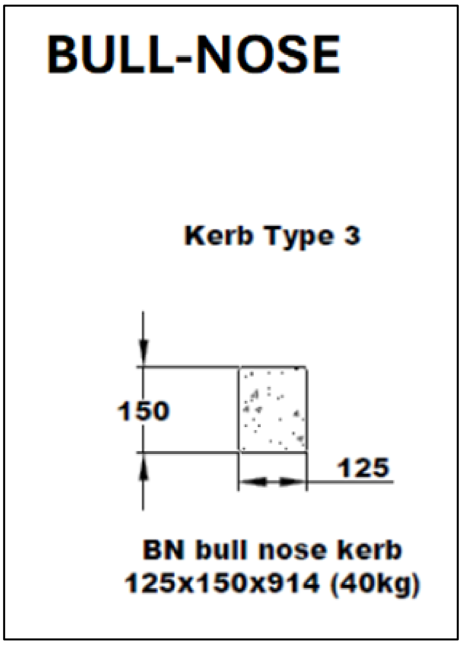

Figure 3-12: Bull-Nose kerb standard dimensions

3.5.2 TLX Results

From Figure 3-13 and Table 3-6 it can be seen that the Physical group found the increasing kerb upstand height more effortful, with reported workload scores raising from 15 (Medium) to 62 (High). Between the 60mm and 100mm high kerbs reported workload increased by 32%.

In contrast, the Low Vision group (cane and guide-dog) found the increasing kerb upstand height easier to traverse, with reported workload decreasing from 40 (Intermediate) to 17 (Medium) as the kerb upstand increased from 25mm to 50mm. There was no change in reported workload between the 50mm and 60mm kerb heights. However, they reported a higher workload of 34 (Intermediate) when the upstand was set at 100mm.

Similarly, the Moderate Vision group (retinal and macular degeneration) reported an Intermediate level of workload for the 25mm high kerb but not as high as the Low Vision group (31). They also reported a Medium workload of 17 for both the 50mm and 60mm kerb heights and a slight increase in workload for the 100mm kerb (25).

The baseline control group reported low workload for all kerb heights.

Table 3-6: Bull-Nose kerb profile overall perceived workload TLX ratings

Kerb	PHYSICAL	LOW VISION	MODERATE VISION	BASELINE
BN25	15	40	31	4
BN50	29	17	17	5
BN60	47	17	17	8
BN100	62	34	25	9

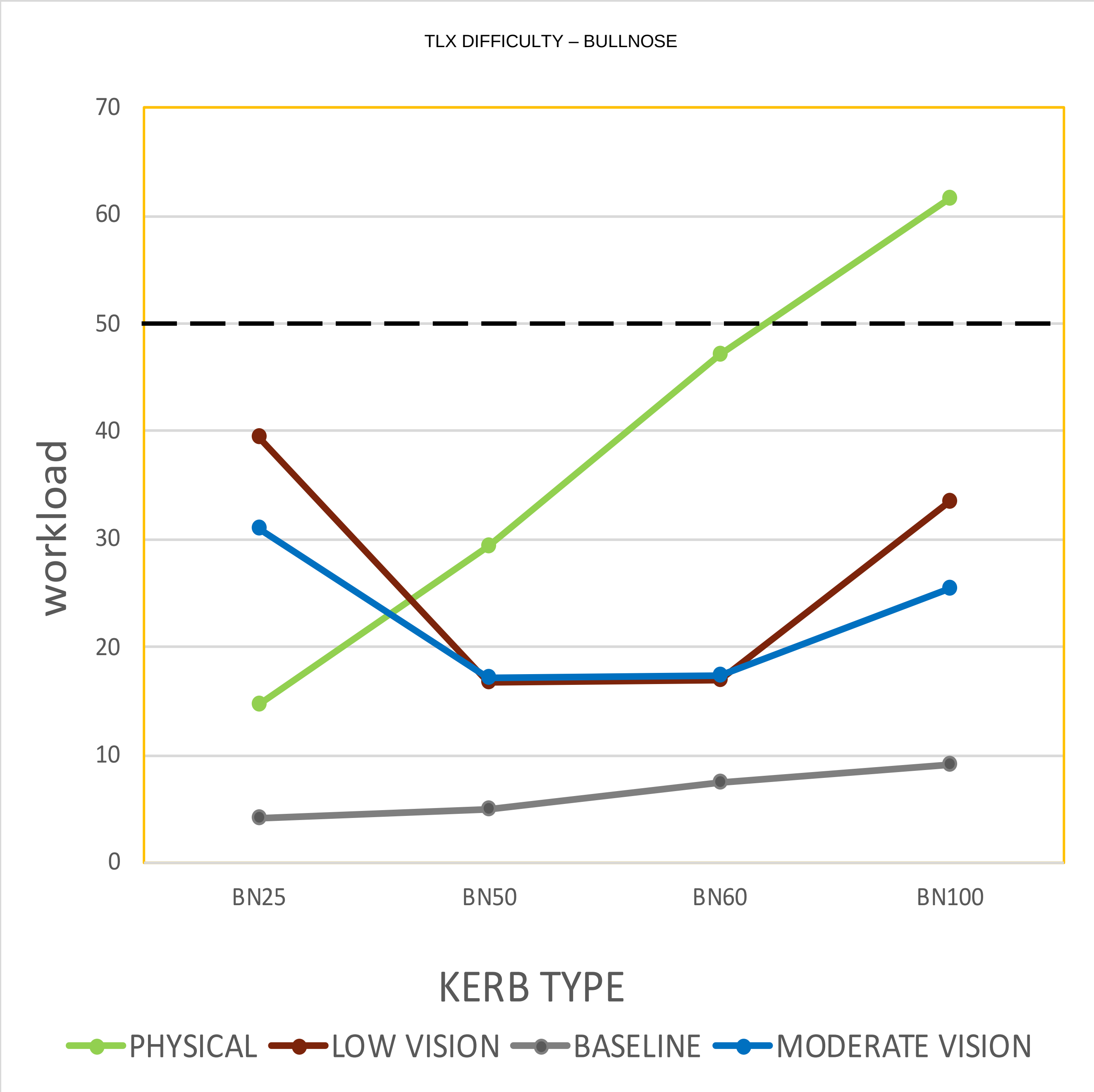

Figure 3-13: Bull-Nose kerb overall perceived workload TLX rating results

3.5.3 Qualitative Findings

3.5.3.1 Vision Group

Participant K2 (Low Vision, cane) noted that he was able to detect the 25mm kerb upstand but stated: “it is low”.

Participant K2 noted that the 50mm kerb upstand was more detectable than the 25mm upstand. Although they also detected the 60mm kerb upstand their preference was for the 50mm due their perception that it required less overall workload to traverse. They further noted that they felt the 100mm was too high.

Figure 3-14: Low Vision participant with cane on the Bull-Nose kerb

3.5.3.2 Physical Group

Participant K5 (Low Physical, wheelchair) stated:

“It [25mm] was easy and straightforward”

They were able to traverse the kerb without extending the third wheel at the 25mm kerb upstand height without stress or frustration.

Participant K5 was unable to traverse up and down the Bull-Nosed kerb at 50mm without the extended third wheel. They were unable to traverse the 60mm with or without the third wheel attached to their chair and they would not attempt the 100mm.

Participant K5 (Low Physical, wheelchair) attempted the 100mm, but acknowledged it was a hazardous movement which would need the right conditions and timing to make the movement possible, stating:

“it's possible... I can't reliably do it. I failed doing it dynamically once and I managed the second time. It's all a question of… you've got to get the right timing…”

“I would actively look for a drop kerb rather than doing this”

Figure 3-15: Low Physical participant in wheelchair on the Bull-Nose kerb

3.5.4 Analysis

From the TLX and Qualitative results it can be seen that the 25mm kerb was detectable by all participants, however, the mental workload for the Vision groups was higher than the mental and physical workload for the Physical group.

However, for this kerb profile, the guide dog was not aware of the kerb while coming down. In addition, it was noted it was much easier to detect the kerb at this height using the cane than with the guide dog.

As the kerbs increase to 50mm, however, more workload was required by the Physical group than the Low and Moderate Vision groups. At this point the Low and Moderate Vision groups found it easier to find and traverse the kerb whereas the Low Physical (wheelchair) group began to have difficulty traversing the kerb and required the third wheel to be fitted to their wheelchair to traverse it.

The Bull-Nose kerb had the lowest reported workload scores at the 50mm height than any other kerb type.

At 60mm the ability for Low Physical users to traverse the kerb reduced considerably with one participant unable to traverse the kerb even with the third wheel attached to their chair.

For all participants, including the baseline, the 100mm kerb was considered to be an undesirable increase in workload. However, it scored marginally lower than the Half-Batter kerb at the same hight.

For the Low Physical (wheelchair) users, inside safe controlled laboratory conditions, 100mm was a near impossible height to cross.

From the Qualitative and graphic results (above) we can conclude from this that there is evidence that for the Low Visual and Moderate Visual groups that overall workload decreased as kerb height increased from the 25mm to the 50mm upstand. The workload remained relatively constant between 50mm and 60mm upstand before the workload again increased as the difficulty went from being about detecting the kerb to the physical effort of actually crossing it at 100mm. For visually impaired participants the workload varied dependant on the participants visual aid or capability i.e. cane, guide dog, or visual capability.

From the Qualitative and graphic results (above) we can conclude from this that there is evidence that for the Physical group that overall workload increased linearly as the kerb height increased. However, it should be noted that the increase in workload was more pronounced for the Bull-Nose kerb type compared to the Full-Batter. For wheelchair users in particular this was primarily driven by the users perception that there was a greater potential risk that they would topple, tip or that the movement would cause significant vibration and hence pain and discomfort. This corresponds to the data shown for mental workload in Figure 3-3 for Bull-Nose kerbs which is considerably higher than that of Full-Batter kerbs due to the vertical slope associated with Bull-Nose kerbs preventing an easier and smoother crossing than shallower kerb types.

3.6 Cycle Segregation Kerb

3.6.1 General

Participants experience with cycleways was explored as part of Phase 3. To continue this in Phase 4 a Cycle Segregation kerb was included in the testing.

A Cycle segregation kerb is a 205mm high by 290mm wide solid stone or concrete block with a 45 splay starting 129mm from the base. Cycle segregation kerbs are often double sided as show in Figure 3-16. The full height of the kerb is not used as the upstand, only the exposed top 20mm – 50mm. The remaining height is beneath the surface and does not influence the experience of traversing the kerb.

Cycle Segregation kerbs are found in locations where the pavement on either side is the same level, where the kerb forms a raised dividing ridge between these two surfaces to assist in defining the space. Usually this arrangement is utilised to define the separation of a cycle track and conflicting carriageway of vehicular or pedestrian traffic. However, in this experiment the kerb was set up in a scenario where the pavement on one side was raised compared to the other. This arrangement was compatible with the experimental rig, allowing the kerb to fit safely in the cradle. The platform to the rear of the kerb was raised level to the top of the kerb while the platform at the front maintained a lower level to allow for the proposed movement. As in other tests the participants were asked to ascend and then descend the kerb and provide feedback.

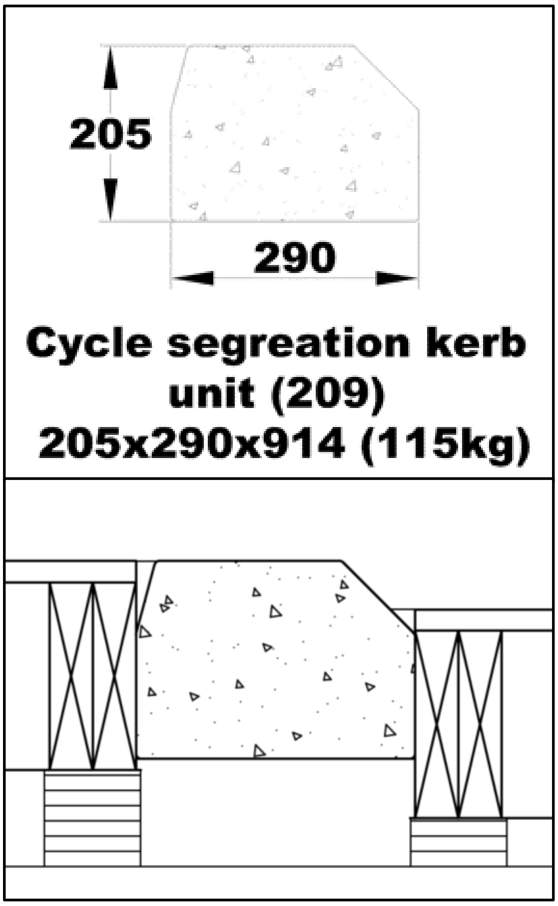

Figure 3-16: Cycle Segregation kerb dimensions with illustrative test platform location.

3.6.2 TLX Results

From Figure 3-17 and Table 3-7 it can be seen that the Physical group found the highest kerb tested (50mm) required the highest workload (33, Intermediate workload). The 20mm and 25mm kerb heights were easier to traverse with similar reported workload scores (11, Medium workload and 9, Low workload respectively).

Both the Low and Medium Vision groups reported Intermediate levels of workload for the 20mm and 25mm kerb heights, the Low Vision group reported slightly higher workloads than the Moderate Vision group. Both groups found the 50mm height kerb easier to detect reporting an Intermediate workload score of 17.

The baseline control group reported a Low workload for all kerb heights.

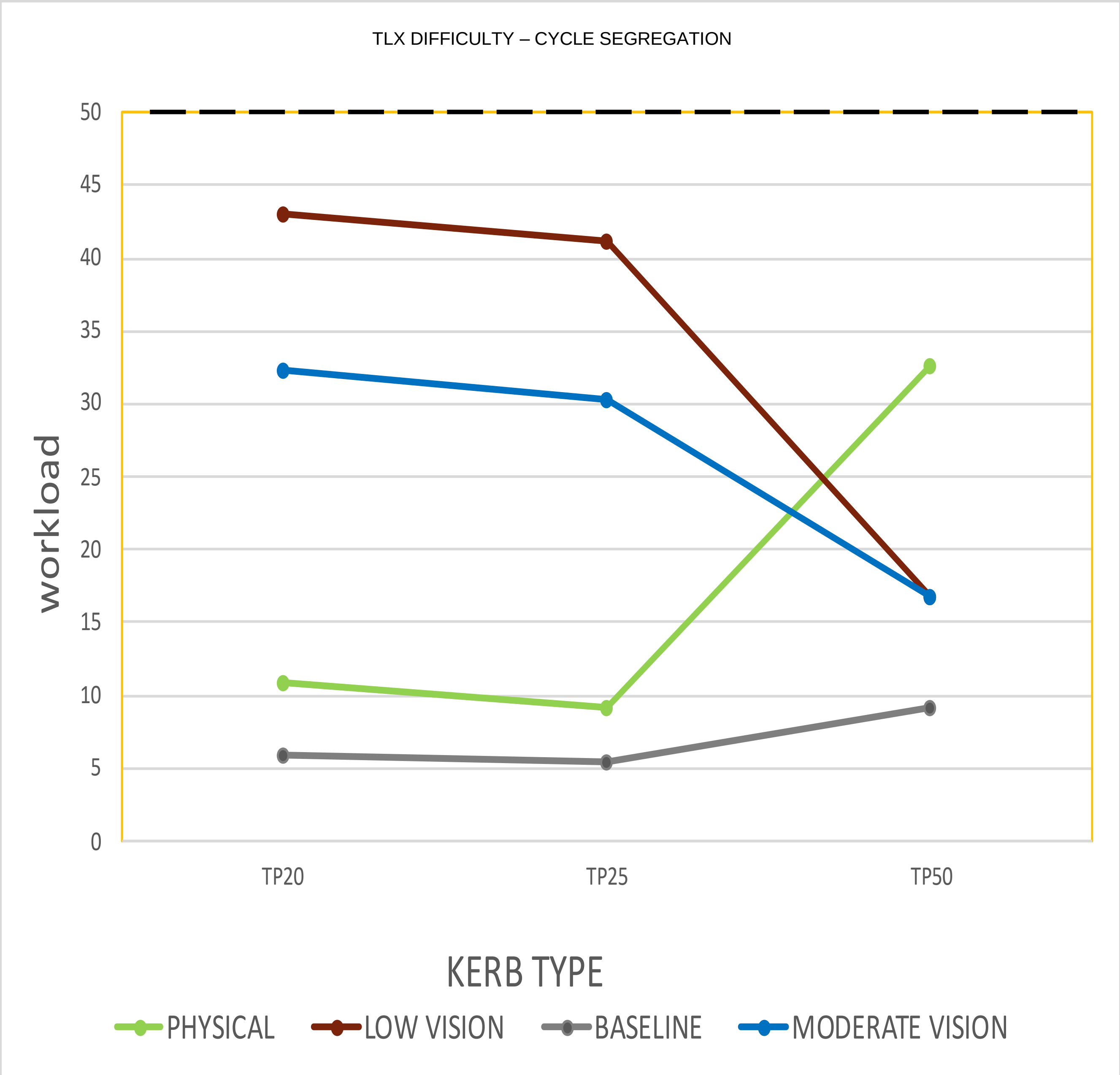

Figure 3-17: Cycle Segregation kerb overall perceived workload TLX rating results

3.6.3 Qualitative Findings

3.6.3.1 Vision Group

Participant K3 (Low Vision) noted that 20mm upstand was quite low, flat, and not easily detectable. Participant K2 (Low Vision) agreed and stated that the 50mm kerb upstand height was easier to detect and traverse.

Participant K11 (Low Vision, cane) stated of the 50mm upstand:

"..it's better than 20mm and 25mm…"

Figure 3-18: Low Vision group participant with cane on the Cycle Segregation kerb

3.6.3.2 Physical Group

Participant K5 (Low Physical, wheelchair) noted that 25mm was easy to traverse, with a bit more effort required compared to the 20mm upstand. They noted that traversing this height was easier with the extended wheel, stating:

"25[mm] is a wee bit harder without my wheel – but its ok ,…"

"It's easier with the wheel than without but its ok…"

However, Participant K18 (Moderate Physical) felt that 25mm was too low and "not appropriate". This was determined to be unrelated to the participants physical capability and more of a general comment on their perception of the kerb height being used in streetscaping in general.

At the 50mm upstand Participant K5 was unable to traverse the kerb, with or without the extended wheel.

Participant K5 (Low Physical, wheelchair) stated about the 50mm kerb upstand:

"No, I wouldn't even think about this. I think about it slightly …I see that as less of an issue than if it was vertical..."

"I wouldn't try and cross it at an angle...for some reason, it does seem that that angle helps. I'm not sure why, but it does seem to."

Due to the kerb shape the participant found it difficult to dynamically assess whether the kerb would be traversable or not. This could lead the user misjudging the situation and coming into conflict with other user types.

Figure 3-19: Low Physical group participant in wheelchair on the Cycle Segregation kerb

3.6.4 Analysis

The quantitative and qualitative results suggest that the Low Vision group found the 20mm kerb upstand difficult to detect. They scored it a 43 (Intermediate) workload, equal highest with the 25mm Half-Batter kerb. Low Vision participants described the kerb at this upstand as 'low and flat'.

Interestingly the 25mm upstand was preferred over the 20mm upstand by the Physical group, with some noting that the 20mm kerb felt too low. This is the only occasion where an increase in kerb upstand resulted in a decrease in workload for the Physical group, and the only occasion where either of the Vision or Physical groups rated a kerb as requiring a Low workload.

The Vision groups found the 20mm and 25mm heights to require an Intermediate workload, with the 25mm scoring marginally lower than the 20mm height. The participants felt both heights were too low.

However, at 50mm the workload levels reversed. The Low Visual participants finding the kerb a much lower workload, scoring amongst the lowest of the workloads they ranked. The workload reported by the Physical group participants increased to an Intermediate level, with the Low Physical group participants finding the kerb difficult and with one participant unable to traverse the kerb even whilst using the third wheel.

From the Qualitative and graphic results (above) we can conclude from this that there is evidence that for the Low Visual and Moderate Visual groups that the conspicuousness of this type of kerb greatly increased as the height of the kerb increased to 50mm upstand. This was the same for all participants independent of their visual aid or capability.

From the Qualitative and graphic results (above) we can conclude from this that there is evidence that for the Physical group that beyond 25mm upstand that the participants found this style of kerb more difficult to dynamically assess and cross if they were able to at all.

4 Results Analysis

4.1 Equal Workload Point

During the analysis of the quantitative TLX workload data, it was observed that the workload of the Vision groups would always cross the workload of the Physical group. For each kerb type this point would be somewhere between the 25mm and 50mm kerb upstand. Theoretically, this point would be the location where both the Vision and Physical groups have an equal level of perceived workload.

Following the method described in ‘Appendix A.1 Linear Interpolation of Results to mathematically interpret’ this point was calculated for each kerb type. It was found that a kerb upstand in the range of 40mm - 48mm could be of equal workload for both the Visual and Physical groups. Considering engineering standards this would translate to 40mm or 45mm upstands.

The equal workload at this point would be between 23 and 29 on the TLX workload scale depending on kerb profile. This equates to a Medium level of workload on the category scale used in this report.

4.2 Statistics

The TLX quantitative data was statistically analysed using the methods described in Appendix A.3.

When considering the Low Vision group, the test between Half-Batter 50mm and 25mm kerb heights shows there is statistically significance difference at a greater than 95% level of confidence.

There was found to be a lack of difference between the Low Vision and Moderate Vision group scores which is likely attributable to the overall similarity of scores between these two groups. These differences are too small to be detected at the test power and sensitivity.

For the Physical group, there is evidence of statistical significance of differences in Full-Batter 50mm and Half-Batter 25mm results with a confidence level greater than 99%. Similar outcomes were shown between other combinations.

The purpose of this exercise was to determine whether the differences between observed perceived workload ratings for different conditions (Kerb x height) were not due to chance, at a significance level of 5 in 100 ($P<0.05$).

4.3 Analysis of Visual and Physical Results

When considering the quantitative and qualitative results across all kerb profiles and upstand heights the following patterns were detected:

- Perceived workload ratings were predominantly a combination of physical and mental effort. The amount of mental effort reported increased with reported physical effort.
- The 20mm - 25mm kerbs were detected and traversed easily by the Low and Moderate Physical capability participants. There was no preference for any of the kerb types with workload scores similar across all types.
- The 20mm - 25mm kerbs were detectable by the Low and Moderate Vision capability group participants, but with more difficulty than higher upstands. Occasionally they were not noticed by guide dogs when the participant was stepping down off a kerb.
- The Cycle Segregation kerb, in particular, was hard to detect by the Low and Moderate Vision groups at 20mm or 25mm but they found the 50mm Cycle Segregation kerb height significantly easier reporting a reduction in the overall workload score.
- The 50mm – 60mm kerbs were not traversable by wheelchair users without the use of a third wheel attached to the chair or additional assistance.
- The 50mm kerbs were detectable and preferred by Low and Moderate Vision participants. There was a preference for the Half-Batter and Bull-Nose vertical faces over the Full-Batter.
- The 60mm kerbs were found by the Low Vision participants to require the lowest workload. However, combining workload scores from both Low Vision and Moderate Vision groups, the 50mm kerbs were preferred by visually impaired participants overall.
- The 100mm kerbs (Bull-Nose and Half-Batter) were considered hard to traverse and frustrating by all user groups, even the baseline group.
- Overall, the statistical tests produced results that were consistent with the Qualitative results and integrated analysis.

5 Discussion

5.1 General

This Phase 4 study report is the final chapter in a series of previous reports, described in Section 1.2, and it is important to consider the prior phases in the interpretation of the Phase 4 results.

Each methodology provides different qualities and balances of evidence, but the triangulated results provide a compelling narrative around the difficulties and contrasts of visually and physically impaired users.

Considering the mix of qualitative and quantitative results and their statistical significance it is possible to have confidence in the findings of the Inclusive Kerbs Study.

5.2 Integration with Phase 1 - Comparison with Key Literature

Key previous research identified in Phase 1 was ‘Effective Kerb Heights for Blind and Partially Sighted People’ (Childs et al. 2009). This work, commissioned by the Accessibility Research Group for The Guide Dogs for the Blind Association was carried out by the Civil, Environmental, and Geomatic Engineering, University College London using the Pedestrian Accessibility Movement and Environment Laboratory (PAMELA) facility.

This work aimed to establish the effective kerb heights for blind and partially sighted people in the context of shared space developments, which were being used and developed during the time this study was being carried out, that reduced or eliminated kerb upstands to reduce the delineation of vehicles and pedestrians and remove indications of priority (see Manual for streets, Section 2.9, 2010).

Subsequent experience with shared space schemes has proved that low vision and moderate vision pedestrians tend to be brought into conflict with motor vehicles, and that kerb upstands and unlevel surfaces could be a hazard to low physical mobility users and those of low mental capability.

The Childs study used Bull-Nose and Half-Batter kerb profiles between 20mm and 120mm increasing in 10 mm increments up to 80mm, then jumping to 120mm.

All 36 participants were at varying levels of reduced visual capability, including both guide dog and long cane users. All had experiences of independent use of streets. There were no physical mobility or other capability varying participants.

Procedurally, participants experienced traverses of the PAMELA slabs with varying incidents of planar encounter (45° and 90°) with various kerb heights. Performance was recorded as categories of encounter. Detection was measured using a 10 point self-report verbal scale. Anxiety was also recorded as a 10 point self-report verbal scale; before, during and after.

Results were analysed from detection rates, anxiety levels, and approach angles.

- Participants showed higher confidence in detecting 80mm and 120mm kerbs (82% and 84% respectively).
- Detection confidence dropped for kerb heights of 60mm or less with 13 failing to detect 20mm kerbs.
- Participants were more confident when approaching kerbs from below rather than above.
- Stepping up the kerb resulted in higher detection confidence and lower anxiety compared to stepping down.
- Half-Batter kerbs were slightly easier to detect than Bull-Nose edge kerbs.
- Participants generally reported low anxiety levels throughout the experiment, dropping over time, irrespective of height.
- No significant difference in detection or anxiety scores, based on approach angle.
- Statistical differences were found in detection and anxiety scores between Half-Batter and Bull-Nose edge profiles. These were related to the order in which the conditions were presented (Day 1 vs Day 2).
- The study was unable to differentiate the detectability or effect of 50mm kerbs.
- The study also identified that after 40mm detection rates improved, with two non-detections for 40mm, one at 50mm, and zero at 60mm.

Childs et al. results were broadly consistent with the Phase 4 trials, but in comparison to this Inclusive Kerbs Research Study the methodology was severely restricted.

In particular, the self-report scales of anxiety and detection were psychologically simplistic and do not bear comparison with the comprehensive studies of this Phase 4 and the qualitative results of the Phase 3 results. The Childs study did not address the anthropological “lived experience” of navigating the streets, the participants were not asked about this and did not leave the controlled environment of the building (Davis, 2007).

Hence, despite prior work Childs et al. and others, there is still considerable uncertainty surrounding the use, upstands, and profiles of kerbs within road developments where individuals of varying functional capability are expected to navigate. Guidance, although detailed, often fails to cite recent academic research to evidence proscriptive guidance.

The Childs study also did not address other capability variations such as physical movement, mental, or hearing issues, and was not based on the guidelines of Inclusive Design (Langdon and Thimbleby, 2010).

A wider range of kerb types were assessed and utilised throughout this Inclusive Kerbs Research Study, that also recorded the participants verbal comments during their encounters with different kerbs, including perpendicular, up kerb, and down kerb, and when asked to traverse the kerb width.

Unlike the ‘Effective Kerb Heights for Blind and Partially Sighted People’, the Inclusive Kerbs Research Study participants were presented with all conditions in a randomised order, reducing the impact of comparisons between different kerb experiences.

This Inclusive Kerb Study represents a multiple convergent methodology of research; combining civil engineering data; qualitative investigation of the lived experiences of kerb users; and laboratory experiments in controlled conditions, of disabled users’ reactions to kerbs.

5.3 Integration with Phase 2 – Comparison with Surveyed Kerb Heights

Phase 2 identified the engineering design considerations for kerbs, including delineation, gradient control, drainage control, and very low speed vehicle restraint. It identified that a delineator kerb between 12mm and 20mm in height is currently prescribed for segregated cycle tracks in the Traffic Signs Regulations and General Directions 2016 (Department for Transport, 2016) (TSRGD). It noted, however, that some subsequent design guidance indicates such a low profile may be disregarded by pedestrians and is difficult to maintain.

From the results of both Phase 3 and this Phase 4 assessment it can be shown that the delineator upstand heights in the TSRGD will have a high workload for the visually impaired. It can also be shown that the kerb upstand heights of 100mm or greater designed to act as minor restraints against slow moving vehicles significantly increase the workload for all users and to an impossible level for wheelchair users.

During Phase 2 the upstand and profile heights of kerbs around the City of Edinburgh were surveyed. The lowest kerb surveyed was 40mm in a new build commercial area. The highest kerb was 140mm in the city’s Old Town. Across all areas surveyed it was found that the average upstand was approximately 91mm, with a standard deviation of 23mm.

Applying the results of the Phase 4 research, the kerbs surveyed in Phase 2 would therefore likely pose at least Medium workload on all impaired users and High or Intermediate levels of workload on physically impaired users. All kerbs surveyed in Phase 2 should be detectable by visually impaired users.

In preparation for Phases 3 and 4 of the research, Phase 2 prepared and tested the interview methodologies used in Phase 3 and conducted quantitative analysis on data from the Family Resources Survey, 2019-2020 (National Statistics, 2021) to identify the percentages of the Scottish population with capability difficulties. This provided the theoretical ideal percentages needed for each of the capability difficulties for the research to match the wider Scottish population. This showed that 45% of those with functional difficulties identified as having mobility and dexterity issues, and 10% as having issues with vision.

Phase 2 also surveyed the footway and carriageway gradients, ambient noise level, and contrast of the kerb against the footway and carriageway. These areas of research were not continued in Phase 4 due to project constraints and the need to reduce variables to focus on the upstand height. However, these data sets could form part of further research into kerb detection and navigation.

5.4 Integration with Phase 3 - Comparison with Lived Experiences

Phase 3 focused on gathering real world lived experience qualitative data from interviews and site visits. Participants were asked in detail about their experience with current streetscaping, and kerbs in particular. They were then taken to three different sites within Edinburgh and asked to provide their commentary on navigating and traversing the kerbs and surrounding street. Their recorded commentaries provided insightful and detailed reports about the lived experience of individuals' dealing with capability variations on Scottish streets.

These holistic results covered a wide range of interrelated physical contexts and considerations showing that the ability and decision to successfully interact with streetscaping and kerbs depends on a wide variety of factors.

Key Phase 3 findings included:

1. Creating conspicuous edges is essential to addressing the challenge of navigation for visually impaired users.
2. Raised edges, such as kerbs, can form barriers to mobility, leading to risks, frustration, and longer journey distances.
3. Training for user groups with functional impairments is often not sufficient, widely available, or up to date with modern streetscaping styles.
4. The placement design of crossings is very important as these are the safest method for functionally impaired users to cross.
5. Route planning resources are required to assist users' journeys, identifying inclusive design features.

When considering these with the Phase 4 results it can be evidenced there are distinctions and similarities of outcomes between visually impaired groups and physically impaired groups as they relate to the specific kerb height and type issues experienced by each user group.

Both visually impaired and physically impaired users evidenced a reluctance to interact with kerbs under normal circumstances. During the site visits the participants were presented with a kerb crossing location, they would assess the crossing situation and begin considering alternative strategies, rather than take the direct route across the kerbs. This often involved travelling along the road to find a more acceptable place to cross, such as a controlled crossing. If no such place was available their last resort was to ask for assistance.

From the site discussions and interviews it was reported by both groups that there were too few suitable crossings and that they were often not correctly configured to meet the needs of impaired users.

Within Phase 4 kerbs of 100mm were shown to be difficult and frustrating for all, and this extended to the baseline group. In Phase 3 this was also reported, with visually impaired participants reporting their concerns about the drop of kerbs (e.g. sprained ankles). This concern also reflects the finding that visually impaired users found it easier to detect kerbs from below than above. Physically impaired participants expressed frustration during their use of high kerbs in local residential settings.

The 50mm and 60mm kerbs were found to be challenging or aversive to wheelchair users during Phase 4, over the range of kerb profiles, with and without the assistance of a third wheel. The nature of this challenge was both psychological, related to anxiety, and also ultimately related to the potential physical injury form toppling, tipping or vibrating. However, from the interviews in Phase 3 we know that attaching the third wheel to the wheelchair is a timely task and needs to be completed at the start of the journey, meaning the user must know or anticipate using it on a kerb in advance. When attached it protrudes from the wheelchair some distance and it is reported to often cause problems when navigating through areas with pedestrians. Therefore, expecting wheelchair users to rely upon this third wheel (which some do not possess) would not form an inclusive design philosophy.

Interestingly low kerbs were not explicitly identified in Phase 3 as causing issues. However, areas where there is a lack of kerbs (or a delineation of minuscule upstand), such as raised tables and shared spaces, were identified as being an issue for visually impaired participants. In Phase 4 the 25mm kerbs were detected and traversed by both visually impaired and physically impaired groups. However, even these were difficult to detect and occasionally not noticed by some visual groups when approached from above.

Participants experience with cycleways was explored as part of Phase 3, and in Phase 4 a Cycle Segregation kerb, often used to delineate cycleways, was included in the testing. In Phase 3 wheelchair users were concerned about being trapped on a cycleway in the channel between kerbs. Both physically impaired and visually impaired participants reported significant concerns about the behaviour of cyclists in their vicinity. It was universally felt that there was a considerable risk of collision when attempting to cross a cycleway due to the behaviour of cyclists.

In Phase 2 the upstand of the kerbs at the cycleway were determined to be 55mm. In the Phase 4 laboratory trials the Cycle Segregation kerbs were found to be difficult to traverse by the wheelchair participants at 50mm, providing further evidence that these kerbs risk trapping wheelchair users on the cycleway. The 20mm and 25mm Cycle Segregation upstands could be easily traversed by the wheelchair participants but proved difficult to detect by the Visually impaired participants.

Both participant groups, Visually and Physically impaired, in Phase 3 agreed that their preferred method of crossing roads, cycleways, and other civil infrastructure was by seeking formal crossing points, first controlled (with traffic signals) and then uncontrolled crossings (without traffic signals). However, they agreed that these were often few and infrequent, often requiring significant detours in their journeys, especially in residential areas. This resulted in them resorting to cross at locations where the kerbs have an upstand, enduring the discomfort of the process and risking the inability to find or traverse the kerb on the other side.

It was established by mathematical interpolation (A.1 Linear Interpolation of Results) that kerb upstands within the range of 40mm-48mm could potential meet the needs of both the Visual and Physical capability groups by providing a kerb which is detectable and traversable with a moderate amount of workload. However, these upstands have not been tested during this research.

5.5 Discussion Summary

Despite previous studies like Childs et al., there remains significant uncertainty about the use and design of kerbs in road developments for people with varying abilities, especially as the Childs study did not consider other capability variations such as physical, mental, or hearing issues and was not based on Inclusive Design principles. This has not allowed existing guidance to provide robust academic support.

This Inclusive Kerb Study assessed a broader range of kerb types and included participants' verbal feedback on their experiences with different kerbs. This study used a mixed-method approach, combining civil engineering data, qualitative insights from kerb users, and controlled laboratory experiments with disabled users. Over the course of all four phases of the study a total of 33 contributions were made by participants to the study.

Phase 2 and 3 assessed the current condition of in-situ kerbs and gathered qualitative data from interviews and site visits, focusing on participants' experiences with streetscaping and kerbs. Through their interview participants provided detailed commentary on navigating the kerbs and surrounding streets. Their insights highlighted the lived experiences of individuals with varying capabilities, covering a wide range of physical contexts and considerations.

This Phase 4 study concludes a series of previous reports, and understanding these earlier phases is crucial for interpreting its results. Each methodology offers unique evidence, but together they highlight the challenges faced by visually and physically impaired users. The combination of qualitative and quantitative data, along with their statistical significance, supports strong confidence in the findings of the Inclusive Kerb Study.

This phase also extrapolated an untested potential range of kerb heights which could potentially provide an equal workload for both the Visual and Physical capability groups. Phase 1 gave evidence that both 40mm and 50mm are currently allowed in some areas of guidance, and that many guidance documents do not specify any minimum upstands. British standard BS EN 1340:2003 ‘Concrete Kerb Units - Requirements and test methods’ sets out a standard range of kerb dimensions which can be specified on British roads, but not does not specify upstand heights. The safe installation of these requires a minimum of 1/3rd of the height of the kerb to be embedded into the ground, however, it is common for kerbs to be embedded deeper to provide a stronger foundation to increased durability and resilience. Commercially these standard kerbs are available with total height as low as 150mm. The upstand height is, therefore, dependent upon which guidance is applicable and the buried depth of the kerb. On schemes with suitable scale of purchasing bespoke kerbs can also be prepared which can be materially efficient.

6 Conclusions

6.1 General

This study has established evidence that kerbs of different heights and profiles are detected and traversed differently by people with varying abilities. There is now evidence of the contradiction between the needs of visually impaired users and physically impaired users.

For visually impaired participants, the kerb height with the least workload for detection depended on whether the user utilise a cane or a guide dog, or had some vision. Kerbs of 20mm and 25mm were detected, but 50mm was universally and, often noticeably, easier to detect.

However, for those with physical movement challenges, kerbs higher than 50mm caused problems, especially when using wheelchairs or other supportive devices. Kerbs of 20mm and 25mm were preferred to higher kerbs.

Both participant groups, and the baseline, agreed that kerbs with a 100mm upstand were more difficult to cross.

The result from this study backs up the qualitative evidence established in the previous phases of this research study.

The clearest finding of the qualitative outcomes across all phases of this study was that street users find traversing kerbs to be dangerous, physically demanding, frustrating and occasionally frightening. They anticipate technologies, such as mapping apps, which may assist them, but they frequently fall back on carers for assistance. This reduces their ability to leave the house and travel, preventing them from accessing many aspects of society. There is now evidence on kerb heights which could improve this situation.

From these Phase 4 results it was calculated that a kerb upstand in the range of 40mm - 48mm could be of equal workload for both visually impaired and physically impaired user groups. Considering engineering standard tolerances this would translate 40mm or 45mm upstand. However, further testing would be required before any suggestion to recommend these kerb upstand heights in guidance could be made. This report does not set recommendations for statutory bodies but presents information and conclusions which can be used by them to determine the future guidance.

When considering the policy and guidance implications in these results it will be important to remember that all kerbs tested required a level of effort from the participants to traverse; mental and physical. Under real world conditions it is likely that such manoeuvres will be undertaken several times a day under more stressful and hazardous conditions. When establishing kerb upstand guidance, it will be important to consider what would be an acceptable workload compromise based on the intended design objectives and environment.

6.2 Areas for Further Study

During this course of the research study avenues for further research were identified, these included:

- Further user testing with both the Vision and Physical capability groups on 40mm and 45mm kerbs.
- Testing of Cycle segregation Kerbs due to their increasing usage.
- Testing of bespoke kerb profiles to determine if changes in this parameter could assist impaired users.
- Research into lighting dependent challenges (e.g. day and night).
- Research into different weather conditions, including wet and frozen conditions.
- Research into the possibility of enhancing kerbs for those with moderate visual capability levels (e.g. using colour and contrast).
- Research covering a wider range of ages, demographics, and capability variations.
- Research covering different mobility aids (motorised wheelchairs).
- Research into participant fatigue – how detecting, crossing or traversing multiple kerbs or street obstacles over time affects workload perception.
- Research into the design and frequency of controlled and uncontrolled crossings.
- Research into improved wheelchair designs for mechanical stability and kerb crossings.

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A. Appendix A – Analysis and Statistics

A.1 Linear Interpolation of Results

During the analysis of the data, it was observed that the workload of the two groups would at some point cross between the 25mm and 50mm kerb upstand. Theoretically this point would be the location which both the Visually Impaired and Physically impaired user groups would have an equal level of workload.

Assuming the continuing trends of each group it can be mathematically calculated where that location could be using a simple Linear Interpolation to establish the mid-point using the Equation 1.

Equation 1: Linear Interpolation

$$y = y\_1 + (x - x\_1)(y\_2 - y\_1)/(x\_2 - x\_1)$$

Where:

- $x = x\_1 + (x\_2 - x\_1)/2$
- x_1 and y_1 are the first coordinates, and
- x_2 and y_2 are the second coordinates
- x is the point to perform the interpolation
- y is the interpolated value

Note that the Low Vision and Moderate Vision groups' data were combined to simplify the calculation.

This yielded the result in TableApp 1, below.

TableApp 1: Intersection Points

Intersection	Full-Batters	Half-Battered	Bull-Nose	Cycle segregation
x	44.50	47.50	42.50	40.25
y	28.75	29.00	23.75	23.50

The interpolation suggests that a kerb upstand in the range of 40mm-48mm would be of equal Medium workload for both Visual impaired and Physical impaired users' groups. Considering engineering standards this translates to 40mm or 45mm upstands.

Further testing of different kerb upstand heights between 25mm and 50mm, with a focus on the 40 – 48mm range, could collect qualitative information on how users interact with kerbs in this range.

A.2 Cycle Segregation Kerb / Full Batter Kerb Discussion

The Cycle Segregation kerb used in the experiments was a 209 Cycle Segregation Unit from Marshalls.

It is acknowledged that this has a 45 degree splay which would be the same as the Full Batter kerb and that participants experience of the kerb profile face would therefore be similar.

As shown in TableApp 2, below, this similarity is broadly replicated in the results. The difference between the Full Batter and Cycle segregation kerbs from Low Vision and Moderate Vision participants at 25mm being within one workload point of each other. However, at 50mm a variation of 12 to 7 workload points is evident. Looking at the mentally and physically weighted results, TableApp 3 and TableApp 4 shows that both physical and mental attributes played a key part in the visually impaired user groups perceived workloads (as discussed in report section 3.2.2).

For the Physical user group at 50mm the workload was the same for both kerb types, but a difference of 5 workload points is seen at the lower 25mm upstand in favour of the Cycle segregation kerb. Assesment of the weighted scores for the Physical user group suggests this is predominated by the physical workload factor, as shown inTableApp 4. This is particularly evident on the Full Batter Kerb at 50mm where a 10 point increase on physically weighted workload can be observed.

The overall width of the Cycle segregation kerb is 290mm, which is over twice as large as the width of the Full Batter Kerb at 125mm. This suggests that the width of the kerb, in addition to the profile played a significant part in the perceived physical and mental workloads experienced by the users of the kerbs and therefore they were observed and traversed differently to the Full Batter kerb despite the similarities.

TableApp 2: Unweighted Perceived Workload CS vs FB

Overall Unweighted Perceived Workload				
Kerb	PHYSICAL	LOW VISION	MODERATE VISION	BASELINE
FB25	14	42	31	7
FB50	33	29	24	7
CS25	9	41	30	5
CS50	33	17	17	9

TableApp 3: Mental Weighted Perceived Workload CS vs FB

Mental Perceived Workload				
Kerb	PHYSICAL	LOW VISION	MODERATE VISION	BASELINE
FB25	8	37	33	13
FB50	12	24	25	10
CS25	8	38	30	8
CS50	32	14	17	13

TableApp 4: Physically Weighted Perceived Workload CS vs FB

Physical Perceived Workload				
Kerb	PHYSICAL	LOW VISION	MODERATE VISION	BASELINE
FB25	16	27	18	8
FB50	43	27	18	8
CS25	12	36	24	5
CS50	36	13	12	10

A.3 Analysis: Inferential Statistics for TLX findings

A.3.1 NASA-TLX non-parametric Wilcoxon Test

The factors and conditions of the experiment are given in TableApp 5, below.

- Factor 1 is Kerb Type, with four levels.
- Factor 2 is Kerb Height, with five levels.

These constitute the Independent Variables. The Dependent (measured) Variables were the TLX rating scores given by the participants after each trial. The test used was the non-parametric equivalent of the t-test.

TableApp 5: Operationalised kerb size and type table.

Kerb type	Upstand height (mm)				
	20	25	50	60	100
Type 1 - Full-Batter - SP	-	FULLBAT_25	FULLBAT_50	FULLBAT_60	-
Type 2 - Half-Batter - HB2	-	HALFBAT_25	HALFBAT_50	HALFBAT_60	HALFBAT_100
Type 3 - Bull-Nose - BN	-	BULLNOSE_25	BULLNOSE_50	JBULLNOSE_60	BULLNOSE_100
Type 4 – Cycle segregation	CYCLESEGREGATION_20	CYCLESEGREGATION_25	CYCLESEGREGATION_50	-	-

Wilcoxon signed-rank tests were conducted to identify whether the differences in outcomes between kerb types and heights used in the rig experiment were statistically significant. In this study, the measurements are based on the TLX rating scale from low (0%) and high (100%) for mental demand, physical demand, temporal demand, effort and frustration. While the scale for the performance is from poor (0%) to good (100%).

We only present the outcomes that were statistically significant in the TableApp 6 and TableApp 7 below. Significance indicates where the probability of the result is less than $p < 0.05$ (5%) indicated by an asterisk (*). Non-significant results indicate that the result may be due to chance, not that there was no difference. Tests were carried out as 2-tailed, meaning that the direction of difference was not predicted. Any missing data led to the specific comparison being excluded. The full test outputs are in the A.3.2 Wilcoxon Signed Ranks Test, below.

TableApp 6: Wilcoxon Signed Ranks Test Results-1

	HB50_Mean - HB25_Mean	FB50_Mean - HB25_Mean	BN50_Mean - HB25_Mean	CS25_Mean - HB50_Mean	FB50_Mean - HB50_Mean	HB60_Mean - HB100_Mean
Low Vision (5)	0.042*	Non-significant	0.043*	0.043*	Non-significant	0.043*
Moderate Vision (4)	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Physical Group (6)	Non-significant	0.028*	0.027*	0.046*	0.028*	Non-significant

A.3.1.1 Visual groups

While considering the **Low Vision group,** test between Half-Batter 50 and 25 (HB50_Mean - HB25_Mean) there is statistical significance difference between the mean HB50 and HB25 at a greater 95% level of confidence (p-value=0.042).

Still on the low vision, similar outcomes between the following: BN50_Mean x HB25_Mean, CS25_Mean - HB50_Mean, HB60_Mean x HB100_Mean, CS50_Mean x HB100_Mean (See Tables 3 and 4 above).

TableApp 7: Wilcoxon Signed Ranks Test Results-2

	CS25_Mean - HB100_Mean	CS20_Mean - HB100_Mean	CS50_Mean - HB100_Mean	CS_Mean - HB_Mean	CS_Mean - FB_Mean	CS_Mean - BN_Mean
Low Vision	Non-significant	Non-significant	0.043*	Non-significant	Non-significant	Non-significant
Moderate Vision	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Physical Group	0.046*	0.046*	Non-significant	0.028*	0.028*	0.028*

From both the qualitative and quantitative results, we can conclude that there is evidence within the **Low Vision group** for significant differences in the perception of workload between heights 25mm and 50mm, primarily as a result of mental workload. This is likely due to the difficulty in detectability of the lower kerbs below 50mm with canes, dog, or feet. The 60mm -100mm difference is a response to increasing difficulty at 100mm.

The lack of differences between Low vision and Moderate vision is likely attributable to the overall similarity of scores between these two groups. These differences and too small to be detected at the test power and sensitivity.

A.3.1.2 Physical Group

Similarly, for the **Physical group**, there is evidence of statistical significance of differences in Full-Batter 50 and Half-Batter 25 (FB50_Mean x HB25_Mean) with the p-value equal 0.028 (the confidence level greater than 99%). similar outcomes between the following: BN50_Mean x HB25_Mean, CS25_Mean x HB50_Mean, FB50_Mean x HB50_Mean, CS25_Mean x HB100_Mean, and CS20_Mean x HB100_Mean (See TableApp 6 and TableApp 7 above).

From both the qualitative and quantitative results we can conclude from this that there is evidence within the **Physical group** for significant differences in the perception of workload between heights 25mm and 50mm, primarily as a result of physical workload. There is also evidence for differences between the Full-Batter and Half-Batter kerbs at 50mm upstand, attributable to differences in kerb profile and its interaction with wheelchairs, canes, and feet. to differences in physical kerb profile and its interaction with wheelchairs, sticks, and feet.

A.3.1.3 Differences between Kerb Types

We looked at the difference between kerb types without a specific kerb height. The outcomes only showed statistically significant differences for the **Physical group**.

For the Physical group, there was evidence of statistical significance of differences between

- Cycle Segregation and Half-Batter (CS_Mean x HB_Mean);
- Cycle Segregation and Full-Batter (CS_Mean x FB_Mean); and
- Cycle Segregation and Bull-Nose (CS_Mean x BN_Mean),

with each having the p-value of <0.05* significance level (See TableApp 7 above).

A.3.2 Wilcoxon Signed Ranks Test

Wilcoxon signed-rank tests were conducted to identify whether the differences in outcomes between kerb types and heights used in the rig experiment are statistically significant. In this study, the measurements are based on the TLX rating scale from low (0%) and high (100%) for mental demand, physical demand, temporal demand, effort and frustration. While the scale for the performance is from poor (0%) to good (100%).

Descriptive Statistics

Group		N	Mean	Std. Deviation	Minimum	Maximum
Baseline	HB25_Mean	2	7.9200	1.76777	6.67	9.17
	HB50_Mean	2	5.8350	1.18087	5.00	6.67
	HB60_Mean	2	7.5000	1.17380	6.67	8.33
	HB100_Mean	2	10.4200	1.76777	9.17	11.67
	HB_Mean	2	7.9200	.00000	7.92	7.92
	FB_Mean	2	7.7800	1.96576	6.39	9.17
	BN_Mean	2	8.9600	3.53553	6.46	11.46
	FB25_Mean	2	6.6650	2.35467	5.00	8.33
	BN25_Mean	2	6.6700	3.53553	4.17	9.17
	CS20_Mean	2	5.8350	1.18087	5.00	6.67
	CS25_Mean	2	5.4150	.58690	5.00	5.83
	FB50_Mean	2	6.6700	3.53553	4.17	9.17
	BN50_Mean	2	7.5000	3.53553	5.00	10.00
	CS50_Mean	2	9.1650	2.35467	7.50	10.83
	FB60_Mean	2	10.0000	.00000	10.00	10.00
	BN60_Mean	2	10.4150	4.12243	7.50	13.33
	BN100_Mean	2	11.2500	2.94156	9.17	13.33
	CS_Mean	2	6.8050	.19092	6.67	6.94
LowVisi	HB25_Mean	5	45.1660	23.56667	20.00	72.50
	HB50_Mean	5	31.0020	21.38939	8.33	64.17

	HB60_Mean	5	14.8320	8.42414	8.33	28.33
	HB100_Mean	5	36.3320	24.01268	13.33	72.50
	HB_Mean	5	31.8340	17.30327	12.71	59.38
	FB_Mean	5	29.4980	10.49446	13.33	42.22
	BN_Mean	5	26.1260	10.19110	12.92	36.46
	FB25_Mean	5	42.1680	20.42795	12.50	66.67
	BN25_Mean	5	39.4980	26.71496	15.00	68.33
	CS20_Mean	5	43.0020	21.26562	14.17	65.00
	CS25_Mean	5	41.1680	20.75563	14.17	66.67
	FB50_Mean	5	29.0000	12.43539	13.33	45.83
	BN50_Mean	5	14.6660	6.05365	6.67	23.33
	CS50_Mean	5	16.8360	8.66821	11.67	31.67
	FB60_Mean	5	17.3340	7.03258	12.50	29.17
	BN60_Mean	5	16.8360	7.36802	6.67	27.50
	BN100_Mean	5	33.4980	19.97021	18.33	67.50
	CS_Mean	5	33.6660	13.70145	13.33	51.11
MedVisi	HB25_Mean	4	29.1650	13.23086	13.33	41.67
	HB50_Mean	4	28.9600	13.79890	11.67	41.67
	HB60_Mean	4	28.1250	17.69760	15.00	54.17
	HB100_Mean	4	24.1700	15.54563	11.67	46.67
	HB_Mean	4	27.6050	13.85700	12.92	46.04
	FB_Mean	4	26.4575	12.25248	11.67	41.11

	BN_Mean	4	23.5400	9.11022	17.29	37.08
	FB25_Mean	4	28.3350	13.05232	11.67	41.67
	BN25_Mean	4	29.1650	9.83851	20.83	40.00
	CS20_Mean	4	27.0850	9.75135	16.67	38.33
	CS25_Mean	4	22.5000	3.66768	18.33	26.67
	FB50_Mean	4	27.9175	15.06809	11.67	47.50
	BN50_Mean	4	20.6275	9.65560	11.67	34.17
	CS50_Mean	4	23.7500	10.46626	15.83	39.17
	FB60_Mean	4	23.1250	9.18864	11.67	34.17
	BN60_Mean	4	22.5000	7.38868	16.67	33.33
	BN100_Mean	4	21.8725	12.80809	13.33	40.83
	CS_Mean	4	24.4425	6.74999	16.94	31.67
PhyGrp	HB25_Mean	6	13.5567	11.72244	3.00	29.17
	HB50_Mean	6	16.9450	8.31139	6.67	31.67
	HB60_Mean	6	20.0017	10.57965	9.17	40.00
	HB100_Mean	6	36.6683	23.11642	16.67	70.00
	HB_Mean	6	21.7917	7.52618	9.17	32.50
	FB_Mean	6	28.7050	17.96765	5.56	55.56
	BN_Mean	6	33.7850	21.28945	15.00	65.21
	FB25_Mean	6	14.4433	10.80783	4.17	33.33
	BN25_Mean	6	14.5833	10.55117	5.00	27.50

	CS20_Mean	6	10.8350	10.40993	.00	26.67
	CS25_Mean	6	9.1650	5.91495	2.50	18.33
	FB50_Mean	6	29.7233	20.45275	8.33	66.67
	BN50_Mean	6	22.5000	23.19171	7.50	66.67
	CS50_Mean	6	21.5300	15.88465	4.17	45.00
	FB60_Mean	6	41.9467	26.12898	4.17	66.67
	BN60_Mean	6	41.6667	32.50374	16.67	83.33
	BN100_Mean	6	56.3867	22.41414	30.83	83.33
	CS_Mean	6	13.8467	6.51078	3.06	20.56

Ranks

Group			N	Mean Rank	Sum of Ranks
Baseline	FB25_Mean - HB25_Mean	Negative Ranks	1[a]	2.00	2.00
		Positive Ranks	1[b]	1.00	1.00
		Ties	0[c]		
		Total	2		
	BN25_Mean - HB25_Mean	Negative Ranks	1[d]	2.00	2.00
		Positive Ranks	1[e]	1.00	1.00
		Ties	0[f]		
		Total	2		
	CS20_Mean - HB25_Mean	Negative Ranks	2[g]	1.50	3.00

	Positive Ranks	0[h]	.00	.00
	Ties	0[i]		
	Total	2		
CS25_Mean - HB25_Mean	Negative Ranks	2[j]	1.50	3.00
	Positive Ranks	0[k]	.00	.00
	Ties	0[l]		
	Total	2		
HB50_Mean - HB25_Mean	Negative Ranks	2[m]	1.50	3.00
	Positive Ranks	0[n]	.00	.00
	Ties	0[o]		
	Total	2		
FB50_Mean - HB25_Mean	Negative Ranks	1[p]	2.00	2.00
	Positive Ranks	1[q]	1.00	1.00
	Ties	0[r]		
	Total	2		
BN50_Mean - HB25_Mean	Negative Ranks	1[s]	2.00	2.00
	Positive Ranks	1[t]	1.00	1.00
	Ties	0[u]		
	Total	2		
CS50_Mean - HB25_Mean	Negative Ranks	1[v]	1.00	1.00
	Positive Ranks	1[w]	2.00	2.00

	Ties	0[x]		
	Total	2		
FB25_Mean - HB50_Mean	Negative Ranks	1[y]	1.00	1.00
	Positive Ranks	1[z]	2.00	2.00
	Ties	0[aa]		
	Total	2		
BN25_Mean - HB50_Mean	Negative Ranks	1[ab]	1.00	1.00
	Positive Ranks	1[ac]	2.00	2.00
	Ties	0[ad]		
	Total	2		
CS25_Mean - HB50_Mean	Negative Ranks	1[ae]	1.00	1.00
	Positive Ranks	0[af]	.00	.00
	Ties	1[ag]		
	Total	2		
FB50_Mean - HB50_Mean	Negative Ranks	1[ah]	1.00	1.00
	Positive Ranks	1[ai]	2.00	2.00
	Ties	0[aj]		
	Total	2		
BN50_Mean - HB50_Mean	Negative Ranks	1[ak]	1.00	1.00
	Positive Ranks	1[al]	2.00	2.00
	Ties	0[am]		

	Total	2		
CS50_Mean - HB50_Mean	Negative Ranks	0[an]	.00	.00
	Positive Ranks	2[ao]	1.50	3.00
	Ties	0[ap]		
	Total	2		
FB60_Mean - HB60_Mean	Negative Ranks	0[aq]	.00	.00
	Positive Ranks	2[ar]	1.50	3.00
	Ties	0[as]		
	Total	2		
HB50_Mean - HB100_Mean	Negative Ranks	2[at]	1.50	3.00
	Positive Ranks	0[au]	.00	.00
	Ties	0[av]		
	Total	2		
HB60_Mean - HB100_Mean	Negative Ranks	2[aw]	1.50	3.00
	Positive Ranks	0[ax]	.00	.00
	Ties	0[ay]		
	Total	2		
FB25_Mean - HB100_Mean	Negative Ranks	2[az]	1.50	3.00
	Positive Ranks	0[ba]	.00	.00
	Ties	0[bb]		
	Total	2		

HB25_Mean - HB100_Mean	Negative Ranks	1[bc]	1.00	1.00
	Positive Ranks	0[bd]	.00	.00
	Ties	1[be]		
	Total	2		
BN60_Mean - HB100_Mean	Negative Ranks	1[bf]	2.00	2.00
	Positive Ranks	1[bg]	1.00	1.00
	Ties	0[bh]		
	Total	2		
BN100_Mean - HB100_Mean	Negative Ranks	0[bi]	.00	.00
	Positive Ranks	1[bj]	1.00	1.00
	Ties	1[bk]		
	Total	2		
CS25_Mean - HB100_Mean	Negative Ranks	2[bl]	1.50	3.00
	Positive Ranks	0[bm]	.00	.00
	Ties	0[bn]		
	Total	2		
CS20_Mean - HB100_Mean	Negative Ranks	2[bo]	1.50	3.00
	Positive Ranks	0[bp]	.00	.00
	Ties	0[bq]		
	Total	2		
CS50_Mean - HB100_Mean	Negative Ranks	2[br]	1.50	3.00

	Positive Ranks	0[bs]	.00	.00
	Ties	0[bt]		
	Total	2		
FB_Mean - HB_Mean	Negative Ranks	1[bu]	2.00	2.00
	Positive Ranks	1[bv]	1.00	1.00
	Ties	0[bw]		
	Total	2		
BN_Mean - HB_Mean	Negative Ranks	1[bx]	1.00	1.00
	Positive Ranks	1[by]	2.00	2.00
	Ties	0[bz]		
	Total	2		
CS_Mean - HB_Mean	Negative Ranks	2[ca]	1.50	3.00
	Positive Ranks	0[cb]	.00	.00
	Ties	0[cc]		
	Total	2		
BN_Mean - FB_Mean	Negative Ranks	0[cd]	.00	.00
	Positive Ranks	2[ce]	1.50	3.00
	Ties	0[cf]		
	Total	2		
CS_Mean - FB_Mean	Negative Ranks	1[cg]	2.00	2.00
	Positive Ranks	1[ch]	1.00	1.00

		Ties	0[ci]		
		Total	2		
	CS_Mean - BN_Mean	Negative Ranks	1[cj]	2.00	2.00
		Positive Ranks	1[ck]	1.00	1.00
		Ties	0[cl]		
		Total	2		
LowVisi	FB25_Mean - HB25_Mean	Negative Ranks	3[a]	2.67	8.00
		Positive Ranks	2[b]	3.50	7.00
		Ties	0[c]		
		Total	5		
	BN25_Mean - HB25_Mean	Negative Ranks	3[d]	2.67	8.00
		Positive Ranks	2[e]	3.50	7.00
		Ties	0[f]		
		Total	5		
	CS20_Mean - HB25_Mean	Negative Ranks	3[g]	3.00	9.00
		Positive Ranks	2[h]	3.00	6.00
		Ties	0[i]		
		Total	5		
	CS25_Mean - HB25_Mean	Negative Ranks	4[j]	2.50	10.00
		Positive Ranks	1[k]	5.00	5.00
		Ties	0[l]		

	Total	5		
HB50_Mean - HB25_Mean	Negative Ranks	5[m]	3.00	15.00
	Positive Ranks	0[n]	.00	.00
	Ties	0[o]		
	Total	5		
FB50_Mean - HB25_Mean	Negative Ranks	4[p]	3.25	13.00
	Positive Ranks	1[q]	2.00	2.00
	Ties	0[r]		
	Total	5		
BN50_Mean - HB25_Mean	Negative Ranks	5[s]	3.00	15.00
	Positive Ranks	0[t]	.00	.00
	Ties	0[u]		
	Total	5		
CS50_Mean - HB25_Mean	Negative Ranks	4[v]	3.25	13.00
	Positive Ranks	1[w]	2.00	2.00
	Ties	0[x]		
	Total	5		
FB25_Mean - HB50_Mean	Negative Ranks	1[y]	2.50	2.50
	Positive Ranks	4[z]	3.13	12.50
	Ties	0[aa]		
	Total	5		
BN25_Mean - HB50_Mean	Negative Ranks	2[ab]	3.00	6.00

	Positive Ranks	3[ac]	3.00	9.00
	Ties	0[ad]		
	Total	5		
CS25_Mean - HB50_Mean	Negative Ranks	0[ae]	.00	.00
	Positive Ranks	5[af]	3.00	15.00
	Ties	0[ag]		
	Total	5		
FB50_Mean - HB50_Mean	Negative Ranks	3[ah]	3.17	9.50
	Positive Ranks	2[ai]	2.75	5.50
	Ties	0[aj]		
	Total	5		
BN50_Mean - HB50_Mean	Negative Ranks	4[ak]	3.50	14.00
	Positive Ranks	1[al]	1.00	1.00
	Ties	0[am]		
	Total	5		
CS50_Mean - HB50_Mean	Negative Ranks	3[an]	4.00	12.00
	Positive Ranks	2[ao]	1.50	3.00
	Ties	0[ap]		
	Total	5		
FB60_Mean - HB60_Mean	Negative Ranks	1[aq]	3.00	3.00
	Positive Ranks	4[ar]	3.00	12.00
	Ties	0[as]		

	Total	5		
HB50_Mean - HB100_Mean	Negative Ranks	3[at]	3.00	9.00
	Positive Ranks	2[au]	3.00	6.00
	Ties	0[av]		
	Total	5		
HB60_Mean - HB100_Mean	Negative Ranks	5[aw]	3.00	15.00
	Positive Ranks	0[ax]	.00	.00
	Ties	0[ay]		
	Total	5		
FB25_Mean - HB100_Mean	Negative Ranks	3[az]	2.00	6.00
	Positive Ranks	2[ba]	4.50	9.00
	Ties	0[bb]		
	Total	5		
HB25_Mean - HB100_Mean	Negative Ranks	1[bc]	2.00	2.00
	Positive Ranks	3[bd]	2.67	8.00
	Ties	1[be]		
	Total	5		
BN60_Mean - HB100_Mean	Negative Ranks	4[bf]	3.50	14.00
	Positive Ranks	1[bg]	1.00	1.00
	Ties	0[bh]		
	Total	5		
	Negative Ranks	3[bi]	2.67	8.00

BN100_Mean - HB100_Mean	Positive Ranks	2[bj]	3.50	7.00
	Ties	0[bk]		
	Total	5		
CS25_Mean - HB100_Mean	Negative Ranks	1[bl]	2.00	2.00
	Positive Ranks	4[bm]	3.25	13.00
	Ties	0[bn]		
	Total	5		
CS20_Mean - HB100_Mean	Negative Ranks	1[bo]	5.00	5.00
	Positive Ranks	4[bp]	2.50	10.00
	Ties	0[bq]		
	Total	5		
CS50_Mean - HB100_Mean	Negative Ranks	5[br]	3.00	15.00
	Positive Ranks	0[bs]	.00	.00
	Ties	0[bt]		
	Total	5		
FB_Mean - HB_Mean	Negative Ranks	2[bu]	4.00	8.00
	Positive Ranks	3[bv]	2.33	7.00
	Ties	0[bw]		
	Total	5		
BN_Mean - HB_Mean	Negative Ranks	3[bx]	3.67	11.00
	Positive Ranks	2[by]	2.00	4.00
	Ties	0[bz]		

		Total	5		
	CS_Mean - HB_Mean	Negative Ranks	2[ca]	3.00	6.00
		Positive Ranks	3[cb]	3.00	9.00
		Ties	0[cc]		
		Total	5		
	BN_Mean - FB_Mean	Negative Ranks	3[cd]	3.33	10.00
		Positive Ranks	2[ce]	2.50	5.00
		Ties	0[cf]		
		Total	5		
	CS_Mean - FB_Mean	Negative Ranks	2[cg]	1.50	3.00
		Positive Ranks	2[ch]	3.50	7.00
		Ties	1[ci]		
		Total	5		
	CS_Mean - BN_Mean	Negative Ranks	2[cj]	2.50	5.00
		Positive Ranks	3[ck]	3.33	10.00
		Ties	0[cl]		
		Total	5		
MedVisi	FB25_Mean - HB25_Mean	Negative Ranks	2[a]	2.00	4.00
		Positive Ranks	1[b]	2.00	2.00
		Ties	1[c]		
		Total	4		
	BN25_Mean - HB25_Mean	Negative Ranks	3[d]	2.00	6.00

	Positive Ranks	1[e]	4.00	4.00
	Ties	0[f]		
	Total	4		
CS20_Mean - HB25_Mean	Negative Ranks	2[g]	2.00	4.00
	Positive Ranks	1[h]	2.00	2.00
	Ties	1[i]		
	Total	4		
CS25_Mean - HB25_Mean	Negative Ranks	3[j]	2.67	8.00
	Positive Ranks	1[k]	2.00	2.00
	Ties	0[l]		
	Total	4		
HB50_Mean - HB25_Mean	Negative Ranks	1[m]	2.00	2.00
	Positive Ranks	1[n]	1.00	1.00
	Ties	2[o]		
	Total	4		
FB50_Mean - HB25_Mean	Negative Ranks	3[p]	2.33	7.00
	Positive Ranks	1[q]	3.00	3.00
	Ties	0[r]		
	Total	4		
BN50_Mean - HB25_Mean	Negative Ranks	3[s]	2.67	8.00
	Positive Ranks	1[t]	2.00	2.00
	Ties	0[u]		

	Total	4		
CS50_Mean - HB25_Mean	Negative Ranks	3[v]	2.83	8.50
	Positive Ranks	1[w]	1.50	1.50
	Ties	0[x]		
	Total	4		
FB25_Mean - HB50_Mean	Negative Ranks	1[y]	2.00	2.00
	Positive Ranks	1[z]	1.00	1.00
	Ties	2[aa]		
	Total	4		
BN25_Mean - HB50_Mean	Negative Ranks	3[ab]	2.00	6.00
	Positive Ranks	1[ac]	4.00	4.00
	Ties	0[ad]		
	Total	4		
CS25_Mean - HB50_Mean	Negative Ranks	3[ae]	2.67	8.00
	Positive Ranks	1[af]	2.00	2.00
	Ties	0[ag]		
	Total	4		
FB50_Mean - HB50_Mean	Negative Ranks	2[ah]	2.00	4.00
	Positive Ranks	1[ai]	2.00	2.00
	Ties	1[aj]		
	Total	4		
BN50_Mean - HB50_Mean	Negative Ranks	3[ak]	2.67	8.00

	Positive Ranks	1[al]	2.00	2.00
	Ties	0[am]		
	Total	4		
CS50_Mean - HB50_Mean	Negative Ranks	3[an]	2.67	8.00
	Positive Ranks	1[ao]	2.00	2.00
	Ties	0[ap]		
	Total	4		
FB60_Mean - HB60_Mean	Negative Ranks	2[aq]	2.25	4.50
	Positive Ranks	1[ar]	1.50	1.50
	Ties	1[as]		
	Total	4		
HB50_Mean - HB100_Mean	Negative Ranks	1[at]	2.00	2.00
	Positive Ranks	2[au]	2.00	4.00
	Ties	1[av]		
	Total	4		
HB60_Mean - HB100_Mean	Negative Ranks	0[aw]	.00	.00
	Positive Ranks	4[ax]	2.50	10.00
	Ties	0[ay]		
	Total	4		
FB25_Mean - HB100_Mean	Negative Ranks	1[az]	2.00	2.00
	Positive Ranks	2[ba]	2.00	4.00
	Ties	1[bb]		

	Total	4		
HB25_Mean - HB100_Mean	Negative Ranks	1[bc]	3.00	3.00
	Positive Ranks	3[bd]	2.33	7.00
	Ties	0[be]		
	Total	4		
BN60_Mean - HB100_Mean	Negative Ranks	2[bf]	2.50	5.00
	Positive Ranks	2[bg]	2.50	5.00
	Ties	0[bh]		
	Total	4		
BN100_Mean - HB100_Mean	Negative Ranks	3[bi]	3.00	9.00
	Positive Ranks	1[bj]	1.00	1.00
	Ties	0[bk]		
	Total	4		
CS25_Mean - HB100_Mean	Negative Ranks	2[bl]	2.50	5.00
	Positive Ranks	2[bm]	2.50	5.00
	Ties	0[bn]		
	Total	4		
CS20_Mean - HB100_Mean	Negative Ranks	1[bo]	2.00	2.00
	Positive Ranks	2[bp]	2.00	4.00
	Ties	1[bq]		
	Total	4		
CS50_Mean - HB100_Mean	Negative Ranks	2[br]	2.50	5.00

	Positive Ranks	2[bs]	2.50	5.00
	Ties	0[bt]		
	Total	4		
FB_Mean - HB_Mean	Negative Ranks	2[bu]	3.50	7.00
	Positive Ranks	2[bv]	1.50	3.00
	Ties	0[bw]		
	Total	4		
BN_Mean - HB_Mean	Negative Ranks	3[bx]	2.67	8.00
	Positive Ranks	1[by]	2.00	2.00
	Ties	0[bz]		
	Total	4		
CS_Mean - HB_Mean	Negative Ranks	2[ca]	2.00	4.00
	Positive Ranks	1[cb]	2.00	2.00
	Ties	1[cc]		
	Total	4		
BN_Mean - FB_Mean	Negative Ranks	3[cd]	2.33	7.00
	Positive Ranks	1[ce]	3.00	3.00
	Ties	0[cf]		
	Total	4		
CS_Mean - FB_Mean	Negative Ranks	3[cg]	2.33	7.00
	Positive Ranks	1[ch]	3.00	3.00
	Ties	0[ci]		

		Total	4		
	CS_Mean - BN_Mean	Negative Ranks	2[cj]	2.00	4.00
		Positive Ranks	2[ck]	3.00	6.00
		Ties	0[cl]		
		Total	4		
PhyGrp	FB25_Mean - HB25_Mean	Negative Ranks	1[a]	5.00	5.00
		Positive Ranks	4[b]	2.50	10.00
		Ties	1[c]		
		Total	6		
	BN25_Mean - HB25_Mean	Negative Ranks	2[d]	3.50	7.00
		Positive Ranks	3[e]	2.67	8.00
		Ties	1[f]		
		Total	6		
	CS20_Mean - HB25_Mean	Negative Ranks	5[g]	3.00	15.00
		Positive Ranks	1[h]	6.00	6.00
		Ties	0[i]		
		Total	6		
	CS25_Mean - HB25_Mean	Negative Ranks	4[j]	4.00	16.00
		Positive Ranks	2[k]	2.50	5.00
		Ties	0[l]		
		Total	6		

HB50_Mean - HB25_Mean	Negative Ranks	1[m]	5.00	5.00
	Positive Ranks	5[n]	3.20	16.00
	Ties	0[o]		
	Total	6		
FB50_Mean - HB25_Mean	Negative Ranks	0[p]	.00	.00
	Positive Ranks	6[q]	3.50	21.00
	Ties	0[r]		
	Total	6		
BN50_Mean - HB25_Mean	Negative Ranks	0[s]	.00	.00
	Positive Ranks	6[t]	3.50	21.00
	Ties	0[u]		
	Total	6		
CS50_Mean - HB25_Mean	Negative Ranks	1[v]	4.00	4.00
	Positive Ranks	4[w]	2.75	11.00
	Ties	1[x]		
	Total	6		
FB25_Mean - HB50_Mean	Negative Ranks	5[y]	3.00	15.00
	Positive Ranks	1[z]	6.00	6.00
	Ties	0[aa]		
	Total	6		
BN25_Mean - HB50_Mean	Negative Ranks	5[ab]	3.10	15.50

	Positive Ranks	1[ac]	5.50	5.50
	Ties	0[ad]		
	Total	6		
CS25_Mean - HB50_Mean	Negative Ranks	5[ae]	4.00	20.00
	Positive Ranks	1[af]	1.00	1.00
	Ties	0[ag]		
	Total	6		
FB50_Mean - HB50_Mean	Negative Ranks	0[ah]	.00	.00
	Positive Ranks	6[ai]	3.50	21.00
	Ties	0[aj]		
	Total	6		
BN50_Mean - HB50_Mean	Negative Ranks	4[ak]	3.50	14.00
	Positive Ranks	2[al]	3.50	7.00
	Ties	0[am]		
	Total	6		
CS50_Mean - HB50_Mean	Negative Ranks	2[an]	2.50	5.00
	Positive Ranks	3[ao]	3.33	10.00
	Ties	1[ap]		
	Total	6		
FB60_Mean - HB60_Mean	Negative Ranks	2[aq]	2.00	4.00
	Positive Ranks	4[ar]	4.25	17.00

	Ties	0[as]		
	Total	6		
HB50_Mean - HB100_Mean	Negative Ranks	4[at]	3.25	13.00
	Positive Ranks	1[au]	2.00	2.00
	Ties	1[av]		
	Total	6		
HB60_Mean - HB100_Mean	Negative Ranks	4[aw]	2.50	10.00
	Positive Ranks	0[ax]	.00	.00
	Ties	2[ay]		
	Total	6		
FB25_Mean - HB100_Mean	Negative Ranks	4[az]	4.25	17.00
	Positive Ranks	2[ba]	2.00	4.00
	Ties	0[bb]		
	Total	6		
HB25_Mean - HB100_Mean	Negative Ranks	4[bc]	4.38	17.50
	Positive Ranks	2[bd]	1.75	3.50
	Ties	0[be]		
	Total	6		
BN60_Mean - HB100_Mean	Negative Ranks	3[bf]	2.00	6.00
	Positive Ranks	2[bg]	4.50	9.00
	Ties	1[bh]		

	Total	6		
BN100_Mean - HB100_Mean	Negative Ranks	3[bi]	2.33	7.00
	Positive Ranks	3[bj]	4.67	14.00
	Ties	0[bk]		
	Total	6		
CS25_Mean - HB100_Mean	Negative Ranks	5[bl]	4.00	20.00
	Positive Ranks	1[bm]	1.00	1.00
	Ties	0[bn]		
	Total	6		
CS20_Mean - HB100_Mean	Negative Ranks	5[bo]	4.00	20.00
	Positive Ranks	1[bp]	1.00	1.00
	Ties	0[bq]		
	Total	6		
CS50_Mean - HB100_Mean	Negative Ranks	4[br]	3.00	12.00
	Positive Ranks	1[bs]	3.00	3.00
	Ties	1[bt]		
	Total	6		
FB_Mean - HB_Mean	Negative Ranks	3[bu]	2.33	7.00
	Positive Ranks	3[bv]	4.67	14.00
	Ties	0[bw]		
	Total	6		

	BN_Mean - HB_Mean	Negative Ranks	2[bx]	3.00	6.00
		Positive Ranks	4[by]	3.75	15.00
		Ties	0[bz]		
		Total	6		
	CS_Mean - HB_Mean	Negative Ranks	6[ca]	3.50	21.00
		Positive Ranks	0[cb]	.00	.00
		Ties	0[cc]		
		Total	6		
	BN_Mean - FB_Mean	Negative Ranks	1[cd]	3.00	3.00
		Positive Ranks	5[ce]	3.60	18.00
		Ties	0[cf]		
		Total	6		
	CS_Mean - FB_Mean	Negative Ranks	6[cg]	3.50	21.00
		Positive Ranks	0[ch]	.00	.00
		Ties	0[ci]		
		Total	6		
	CS_Mean - BN_Mean	Negative Ranks	6[cj]	3.50	21.00
		Positive Ranks	0[ck]	.00	.00
		Ties	0[cl]		
		Total	6		

B. Appendix B – Experiment Framework

B.1 Consent Form and Information Sheets

B.1.1 Consent Form

The Inclusive Kerbs Study project is investigating the response of capability impaired individuals to kerbs within the road environment. The project has been commissioned by Transport Scotland on behalf of the Scottish Road Research Board (SRRB) and the Department for Transport and is being conducted by Mott MacDonald and Edinburgh Napier University's Transport Research Institute.

There is a necessity to improve inclusion for all in the roadside environment in future updated standards. This introduces a requirement for study and reference of a wider range of functional impairments, not just registered disability. Therefore, this study considers the larger and wider population of people who are functionally impaired in vision, hearing, physical movement, thinking ability, and systemic impairments.

The study may lead to the development of new standards, or changes to existing standards, in Scotland, the UK, and beyond. To better serve the end user of any proposed kerb guidance, the project has a strong focus on the personal experiences of the roadside users with functional impairments.

The project has completed two phases: an initial literature review and a further study considering engineering and human factors. The third interview phase is currently being written.

The project has surveyed a range of existing kerbs in different locations, collecting data on a range of attributes on kerb properties and their settings. The data gathered is used in interviews and allows limited associations to be made between user experiences of kerb interactions and kerb design.

The interviews have been conducted online and onsite. The online interviews focused on the reflective lived experiences of the participant and their reactions to the data and commentaries from site surveys. The onsite interviews brings participants to surveyed kerb locations and asks for their opinion on the presented kerb within the holistic setting. Participant can choose to cross the kerb and street if they feel safe to do so.

The project is now starting a fourth phase in April 2023. The Phase Four laboratory interviews will start in spring at Edinburgh Napier University's North Merchiston Campus. It will involve a safe test platform with interchangeable kerbs and surfaces, to allow different forms and height to be tested quickly.

An initial online interview will be conducted with all new volunteers. There is no obligation on anyone to continue and volunteers can leave at any point.

If you are interested in participating in this study please contact John MacLennan at Mott MacDonald (John.MacLennan@mottmac.com) and Profession Pat Langdon at Edinburgh Napier University (P.Langdon@napier.ac.uk).

B.1.2 Information Sheet

Protocols for the iKerb Experiment

Arrival

The Research Fellow working on the project will welcome the participants. Meet up at Merchiston Main entrance car park on Colinton Road or the bus/train stations as the case may be. The Research Fellow will be there 15 minutes ahead of the scheduled time for the participants.

Parking

The Research Fellow will ensure that the disabled car parking slots are available for the participants who attend the experiment with personal cars close to the waiting room. If a parking slot is required, this will be pre-booked, and details will be passed to the participants.

Waiting Room

The waiting room is the Community Room C 44

Laboratory

The laboratory where the experiment will take place is A25. This will follow the safety guidelines of the lab as directed by the Technicians. There will be housekeeping information for all participants and other attendees on the safety procedures.

Experiment (Tasks)

Based on the Master sheet

Refreshments

Refreshments are provided. The participants will have the refreshments served in Community Room C 44.

Incentives

A £20 M&S voucher will be given as an incentive to each of the participants which will be followed by a thank you email to the participants.

Departure

After the experiments for the day, the Research Fellow will ensure the participants are escorted back to the car park/bus station/train station and ensure a seamless departure to their respective destinations.

Route Options

Option A

From the Car Park close to the Glass Room

↓

Entrance to the Jack Kilby Computer Centre

↓

Turn Left toward A15 using Ramp

↓

Turn Right toward A15, at A15 using Ramp go toward A17

↓ → To lab, Turn Right after the lift

↓ Laboratory A25

To the Waiting/Refreshment room, Join the lift

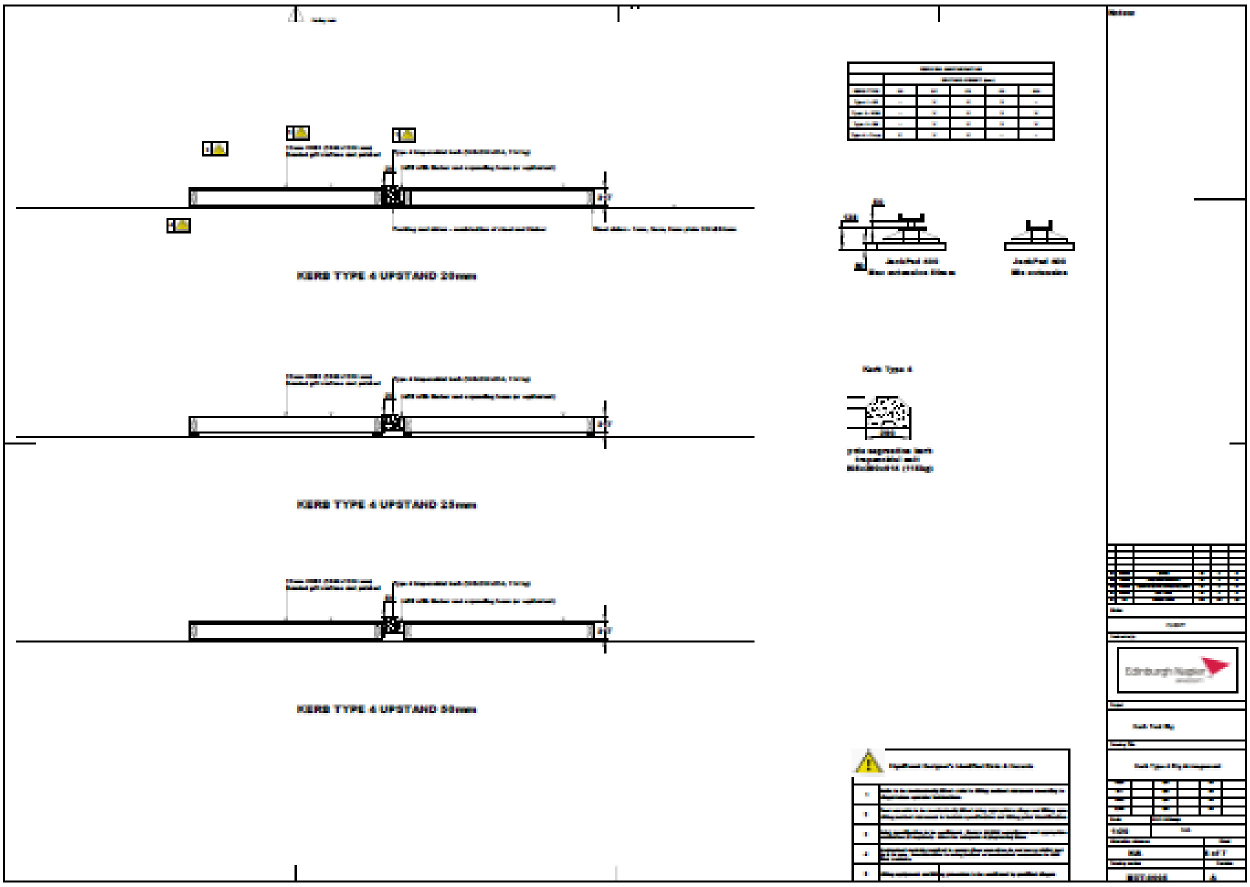
↓

Lift to Level C

↓

Community Room C44

B.2 Rig Schematics



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