DESIGN RESOURCES

DR-20 Functional Reach Capability for Wheeled Mobility Users

Center for Inclusive Design and Environmental Access

DR #20: Functional Reach Capability for Wheeled Mobility Users

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Question: What are the most appropriate heights for locating objects to ensure that they are reachable by wheeled mobility users?

Issue and Importance to Universal Design

An understanding of functional reach capability of wheeled mobility users is required when designing tasks that involve picking and/or placing of objects (e.g., shopping aisles, kitchen shelves) or selecting the optimal locations for controls, devices and objects in the built environment (e.g., elevator buttons, light switches).

Existing Research/Evidences

Reach ranges for wheeled mobility users have been published in academic journals (e.g., Jarosz, 1996; Nowak, 1989; Chari and Kirby, 1986) and government standards for accessibility (such as the U.S. ADA-ABA guidelines). A variety of approaches have been used to characterize reaching abilities. These include range of motion studies (unrestricted arm movement), pick and place tasks, and end-effector reach tasks. However, these research studies present reach data with the person as the reference (i.e. how far people can reach), rather than depicting the impact of design dimensions such as reach height and reach depth on reaching ability (i.e. with the environment as the reference).

As part of the Anthropometry of Wheeled Mobility (AWM) Project, the IDeA Center has been developing a comprehensive anthropometry database of manual chair, powered chair and scooter users in the U.S. (Steinfeld et al., 2010). Measurements of functional reach capability were obtained during an object placement task from 375 wheeled mobility users that were able to perform a functional grasp and reach above the shoulder from among 495 users recruited for this study. Recommendations for acceptable reaching heights and distances in the form of graphical accommodation models were developed.

Quality of Existing Evidence

Current design guidelines and available data on reach for wheeled mobility users do not provide designers with dimensional information for the optimal placement or locations for controls and devices in order to maximize accessibility or depict the impact of reach heights and distances on the level of accessibility.

Existing Design Guidelines

Current accessibility guidelines in the U.S. such as the ADA-ABA Accessibility Guidelines (1), adopt a very simplified model of reaching ability that characterize reach in terms of six discrete scenarios, three depicting forward reach and three side reach. Accompanying each of these conditions is broad reach range that prescribes thresholds or limits for allowable maximum high reach and minimum low reach.

Summary of the AWM findings

Measurement of functional reach capability was assessed using a portable apparatus consisting of five height-adjustable shelves. Shelf heights were set for each participant at their highest and lowest vertical free reach height, shoulder height, and shelves each mid-way above and below shoulder height. The measurement task involved participants reaching out and placing an empty cylindrical canister 75 mm (3.5 in.) in diameter and weighing 56 grams (2 oz.) on a particular target shelf at the maximum possible distance which was recorded using an electromechanical probe. Three different reach directions (forward, sideways and an intermediate of 45 degrees from a sagittal plane at the acromion) were tested. A computational procedure was then used to aggregate data over the entire sample in relation to certain reference planes (i.e., anterior most point for forward reach, lateral most point for lateral reach). Additional details about the methodology and results on the effects of object weight can be found in D'Souza et al. (2009a; 2009b).

Findings were summarized in the form of two graphical charts that depict the 'percent capable' of reaching to a particular height from the floor (shown the vertical axis) and horizontal distance away from the reference plane (shown on the horizontal axis) in either the forward reach direction (Fig. 1) or lateral reach direction (Fig. 2). The vertical and horizontal distances are shown in increments of 100 mm (~4 in.) with horizontal distances in the positive range representing offsets away from the body (i.e. barrier depths when reaching over an obstruction) and the negative range being towards the body measured from the reference point implying that the reach target is brought closer to the person by providing adequate knee and/or toe clearance space beneath the design element (See DR #17: Knee and toe clearances for wheeled mobility users).

Using this design tool, a designer can determine the percentage of wheeled mobility users that might be expected to reach to a 4 in. x 4 in. target location in space for a given height from the floor and offset distance from the reference point. The corresponding percentages are color coded to differentiate regions of reach performance. The dashed lines in the figures show the current ADAAG requirement which specifies a threshold value of 1220 mm when reaching to a target located at the anterior-most point (For detailed comparisons with the ADAAG reach ranges see D'Souza et al., 2009a) .

Note 1: Data presented in this design resource is based on the 235 manual wheelchair users that were able to perform a functional grasp and reach above the shoulder from among 276 manual wheelchair users recruited for the study.
Note 2: These data are based on an object placement task. Care should be taken when applying the findings from this study to other types of reaching tasks, e.g., tasks that require high precision, force application.

Locating Controls & Devices

Design Guidelines for Forward Approach of People Using Manual Wheelchairs

FWD 0lb MANUAL

% OF PEOPLE WHO CAN REACH THE MATRIX CELL INDICATED WHILE HOLDING NO WEIGHT

Graphics Key:

- 0-24% Very Bad Design
- 25-49% Poor Design
- 50-74% Fair Design
- 75-100% Good Design
- Current ADA-ABA Section: 308.2

235 participants	300 11.9	200 7.9	100 3.9	0 0	(-) 100 3.9	(-) 200 7.9	(-) 300 11.9	(-) 400 15.8	(-) 500 19.7	mm / in
1900-1999 [74.9-78.7]	0	0	0	0	0	1	1	1	1	
1800-1899 [70.9-74.8]	0	0	0	1	1	1	1	1	1	
1700-1799 [67.0-70.8]	0	0	2	3	5	7	7	8	8	
1600-1699 [63.1-66.9]	0	3	8	14	18	24	31	35	37	
1500-1599 [59.1-63.0]	2	8	16	23	33	47	57	62	63	
1400-1499 [55.2-59.0]	7	15	26	38	54	67	79	84	87	
1300-1399 [51.2-55.1]	13	20	36	50	69	84	92	97	97	
1200-1299 [47.3-51.1]	16	28	43	62	77	91	96	99	99	
1100-1199 [43.4-47.2]	20	33	53	69	84	91	98	99	99	
1000-1099 [39.4-43.3]	22	39	57	73	87	93	98	99	100	
900-999 [35.5-39.3]	26	41	60	76	90	94	99	100	100	
800-899 [31.6-35.4]	29	43	62	77	90	95	99	100	100	
700-799 [27.6-31.5]	30	43	60	76	89	94	97	97	97	
600-699 [23.7-27.5]	29	41	56	71	81	86	88	88	88	
500-599 [19.7-23.6]	14	20	27	32	37	41	42	43	43	
400-499 [15.8-19.6]	1	2	3	4	5	6	6	6	6	
300-399 [11.9-15.8]	0	0	0	0	0	0	0	1	1	

mm | [in]

vertical distance (from floor)

horizontal distance (from forward-most point)

Data for some or all participants was not collected for reach ranges below points considered unsafe to attempt reaching.

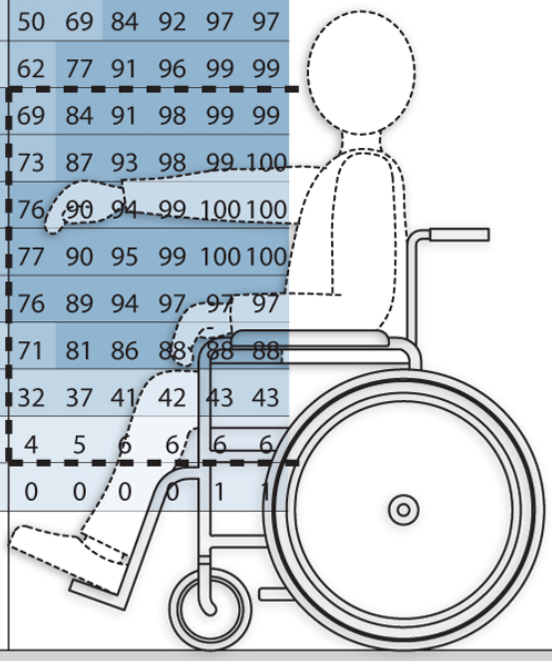

Figure 1: Reaching abilities of manual wheelchair users (*n*=235) expressed as 'percent capable' in the forward reach direction referenced from the anterior-most aspect of the person or mobility device.

Locating Controls & Devices

Design Guidelines for Side Approach of People Using Manual Wheelchairs

SIDE 0lb MANUAL

% OF PEOPLE WHO CAN REACH THE MATRIX CELL INDICATED WHILE HOLDING NO WEIGHT

Graphics Key:

- 0-24% Very Bad Design
- 25-49% Poor Design
- 50-74% Fair Design
- 75-100% Good Design

Current ADA-ABA Section: 308.3

235 participants	900 35.4	800 31.5	700 27.6	600 23.7	500 19.7	400 15.8	300 11.9	200 7.9	100 3.9	0 0	-100 -3.9
1900-1999 [74.9-78.7]	0	0	0	0	0	0	1	1	1	1	1
1800-1899 [70.9-74.8]	0	0	0	0	0	1	1	1	1	1	1
1700-1799 [67.0-70.8]	0	0	0	0	1	1	4	5	6	6	6
1600-1699 [63.1-66.9]	0	0	0	1	3	12	22	29	36	38	38
1500-1599 [59.1-63.0]	0	0	1	4	11	22	36	53	62	64	64
1400-1499 [55.2-59.0]	0	0	2	9	20	32	59	80	86	87	87
1300-1399 [51.2-55.1]	0	1	5	14	28	49	80	94	96	97	97
1200-1299 [47.3-51.1]	0	3	8	18	36	65	92	97	98	99	99
1100-1199 [43.4-47.2]	0	3	11	25	46	78	95	98	98	99	99
1000-1099 [39.4-43.3]	1	3	11	28	53	85	96	98	99	99	99
900-999 [35.5-39.3]	1	5	14	32	57	85	96	99	99	99	99
800-899 [31.6-35.4]	1	5	14	36	58	84	95	99	99	99	99
700-799 [27.6-31.5]	1	5	14	36	58	82	95	98	98	98	98
600-699 [23.7-27.5]	1	6	14	31	50	73	87	90	90	91	91
500-599 [19.7-23.6]	0	3	7	17	27	36	43	47	47	48	48
400-499 [15.8-19.6]	0	0	0	1	3	4	7	9	9	9	9
300-399 [11.9-15.7]	0	0	0	0	0	0	0	0	0	0	0

mm | [in] horizontal distance (from chair edge)

mm | [in] vertical distance (from floor)

Data for some or all participants was not collected for reach ranges below points considered unsafe to attempt reaching.

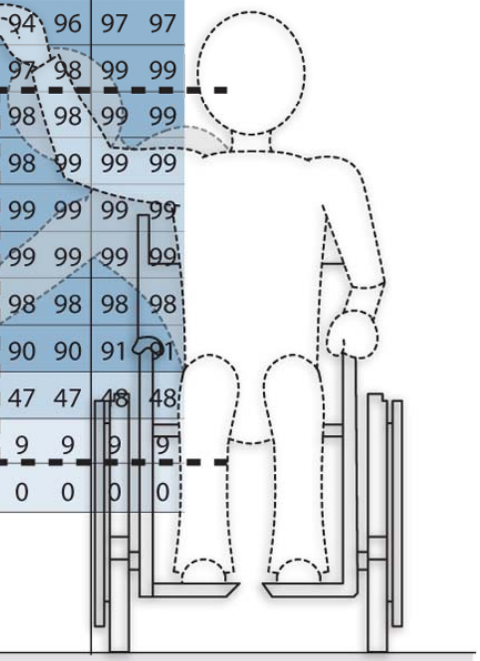

Figure 2: Reaching abilities of manual wheelchair users (*n*=235) expressed as 'percent capable' in the lateral reach direction referenced from the lateral-most aspect of the person or mobility device.

Key findings from this study have been summarized below:

1. Side reach access is far more preferable to forward reach access, which is quite restricted among the wheelchair user population. Targets at locations along the plane of the anterior most point will not be within the reach of a majority of wheeled mobility users, even if the maximum reach height limit were reduced to shoulder height.

2. When forward reach is the only alternative, knee clearance should be provided that allows an individual to extend their legs and front part of their wheelchair beyond the plane on which the target is located. This will allow many more individuals to reach to targets in a forward approach. For the accommodation model of forward reach, the depth of knee clearance needed to accommodate different proportions of the sample can be determined by the columns with negative offset distances and can be interpreted as the increase in 'percent capable' (e.g. 74% or 88% of the sample) for every 100 mm (3.9 in.) increase in available toe or knee clearance.

3. The upper height limit in the current ADA-ABA standard for unobstructed side reach, 1220 mm (48 in.) will accommodate the 99th, 95th and 96th percentile of manual wheelchair, power wheelchair and scooter users in our sample. Thus, there is no need to change that dimension. Our results also indicate that the upper limit of reach could be increased for wheeled mobility users but this may result in limitations for people of small stature.

4. However, a large percentage of the subsample of individuals who had functional reach could not safely reach to the lower limit of 380 mm (15 in.). This lower limit of side reach should be increased to 700 mm (28 in.). We recommend that the lower limit only be applied to controls and devices that are needed for business services (e.g. recharging station for mobile phones or wheelchairs). For long term use in work sites, power strips should be used to provide access to outlets.

5. When designing environments for tasks that require lifting objects, avoid designs that require people to reach to objects above counter height. Adjustable storage units that building occupants can customize to their own needs can improve usability. Devices like sliding shelves that reduce the length of reach tasks are another beneficial strategy.

Examples of Application

Information on reach capability for wheeled mobility users presented in figures 1-2 can help designers identify optimal locations for the object placement under given design constraints of barrier depth or reach direction. Examples of application include the determining of shelf heights in kitchens, shopping centers, etc. that requiring object picking/placing by wheeled mobility users. It also helps specify the appropriate height for controls and dev ices such as light switches and wall outlets.
This information also helps identify tasks that require reach that exceeds the capabilities of most wheeled mobility users, thus needing to be redesigned, for example, by providing additional knee clearance space under counters, for instance.

Research Needs

The data provided here is only a starting point in accessible design for tasks requiring picking/placing of objects. Several other interrelated design parameters such as the orientation, size and shape of the object, direction of force exerted, and operating height, etc. can together affect ones' ability to grasp and apply force, and to varying degrees depending on the type and severity of a person's disability. Additional research is required to quantify the functional reaching abilities for a variety of tasks and activities towards developing more comprehensive and inclusive design criteria.

Acknowledgement
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Relevant IDEA Center Publications

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Relevant Design Resources

Design Resource #16: Clear floor area for wheeled mobility when reaching or grasping.

Design Resource #17: Knee and toe clearances for wheeled mobility users

DESIGN RESOURCES

DR- 20 Functional Reach Capability for Wheeled Mobility Users

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