A Supplementary Study on Adjustment of Accessibility Data Based on Changes in Human Body Size in China

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Abstract. IN response to the continuously declining natural population growth rate and the increasingly severe aging of Chinese society, coupled with the substantial number of individuals with congenital defects, disabilities resulting from diseases, natural disasters, and man-made calamities, the continuous improvement and development of barrier-free design have become an unstoppable social trend. Furthermore, the human body's dimensions serve as the foundation of barrier-free design. However, the current standard implemented in China, GB/T 10000-1988 "Anthropometric Dimensions of Chinese Adults" (hereinafter referred to as "Dimensions" 1988), has been in existence for over 30 years. Moreover, the formulation of the current standard, "Dimensions" 1998, primarily relies on foreign anthropometric data. With the economic development and the evolution of the times, changes in human physical characteristics and the elevation of demands within the disabled community compel us to reconsider and redefine the dimensions of barrier-free design in public spaces for their rationality. A study was conducted, utilizing the measurement items from "Dimensions" 1988 as a basis, selecting college students as measurement subjects, and establishing a database. The measured data underwent correction and derivation based on experimental operational errors, differences in the distribution of sample populations across regions, and variations in age, resulting in a system of human body dimensions necessary for interior design. This endeavor aims to provide more anthropometric data for barrier-free design in China and for barrier-free circulation design in museum settings, simultaneously offering valuable references to meet the new demands for more human-centered barrier-free design among the disabled community. The results indicate that among the 21 measured data points, a small portion of anthropometric dimensions remain relatively stable, whereas significant changes have occurred in the majority of data points.

Keywords: Human size; Body size measurement; accessible design;

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1 Introduction

Currently, the primary methods for anthropometric measurements studied both domestically and internationally include dynamic anthropometric measurement techniques [1], RGB-D-based anthropometric measurement methods [2], checkerboard projection anthropometric measurement methods based on the CAFA-PSPNet human segmentation network [3], anthropometric measurement methods combining convolutional neural networks with curve fitting [4], orthogonal image-based measurement methods [5], CT scan imaging-based three-dimensional measurement methods [6], photographic measurement methods, and anthropometric measurement systems using WeChat mini programs, among other passive non-contact measurement techniques. Passive non-contact measurement methods are simple and straightforward but have indeterminate measurement errors, making them unsuitable for standard or precise measurements [7]. Few scholars have focused their research on proactive measurement methods, which are more applicable to standard or precise measurements.

Therefore, considering the substantial population base of disabled individuals in China, controversies in national anthropometric data standards, and inadequacies in proactive anthropometric research in the country, this paper primarily adopts a proactive measurement approach combined with random sampling, taking into account factors such as time, cost, and result accuracy. Using tools such as laser distance meters, scales, and tape measures, approximately 500 college students aged 18 to 25 were measured for 21 anthropometric items including height, weight, eye height, and shoulder height. The aim is to obtain anthropometric samples, establish a scientific anthropometric table, and obtain revised values for relevant data by comparing and validating them with the 1988 "Anthropometric Dimensions" standards. The measured data will also be compared with the annual national physical fitness survey data to ensure accuracy. The objective is to further enrich and refine the data for the upcoming 2023 "Anthropometric Dimensions" standards, verify controversies in Chinese anthropometric data, provide more support and reference for authoritative data on the elderly and disabled through formula derivation, and offer a basis for designing barrier-free indoor environments in museums. The research findings can be utilized by various sectors of society.

2 The Significance, Content and Method of Research

2.1 Research Significance

Measurements of human body size and shape are an important source of information for a range of scientific fields and applications.[8] Human body dimension data represent a crucial foundational resource, serving as the fundamental basis for product shaping and spatial layout across various industrial design domains. With societal progress and technological advancements, there is a growing emphasis on the application of industrial design and ergonomics. Human body dimension data constitute the prerequisite and foundation for conducting industrial design and ergonomics applications.[9]

Research on human body dimensions holds the following three theoretical significances:

(1) Facilitating the formulation of theories and standards for barrier-free design that align more closely with the characteristics and usage habits of the Chinese population.

(2) The data derived from barrier-free design in museum interiors can serve as a reference for the barrier-free design of other public buildings.

(3) Comparative analysis of pre and post-measured anthropometric data of Chinese adults, combined with existing studies on human body dimensions, can further infer patterns of changes in Chinese physical characteristics.

Simultaneously, it holds the following two practical significances:

(1) Enhancing the suitability and comfort of public building use, ensuring equal rights for disabled individuals to participate in societal activities, and fostering the construction of a harmonious society.

(2) Gaining practical insights through hands-on experience, validating and advancing the findings of previous research. Additionally, the information generated during project implementation will further amplify societal attention towards the development of barrier-free environments and vulnerable groups.

2.2 Research Content and Method

The research contents and methods are shown in Figure 1 below:

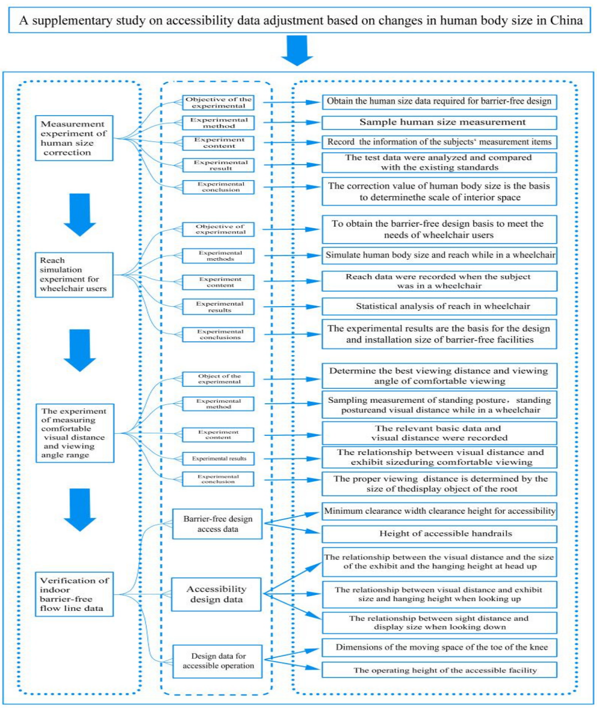

Fig. 1. Research content and process framework (Photo credit: author's own drawing)

3 Human Size Measurement Experiment

3.1 Objective: To Obtain the Data Needed for Barrier-Free Human Dimensions

As previously mentioned, human body dimensions should be adjusted and supplemented every ten years. Currently, China's "Dimensions" 1988 standard no longer accommodates the dimensions of today's society. Furthermore, the latest edition, "Dimensions" 2023, has limited sample coverage of individuals from the 1990s and 2000s, resulting in deviations. Additionally, China consistently emphasizes the importance of constructing a multi-tiered social security system through projects such as "People-Oriented," "Barrier-Free with Love," "Fairness and Uniformity," and "Universal Coverage," to enhance people's well-being and achieve high-quality development. This necessitates minimizing reliance on foreign anthropometric data and enhancing China's own measurement and analysis system for human body dimensions, thereby establishing an accurate and scientific anthropometric table.

3.2 Methods: Human Scale was Sampled

(1) Time and Location: May 2022 - December 2023, Tianjin University.

(2) Participants

The participants consisted of 501 undergraduate students aged between 18 and 25 from Tianjin University, with approximately equal numbers of males and females. The sample size for statistical validity is determined by the allowable error and confidence level. At a given confidence level, the sample size decreases with an increase in the allowable error, while for a given allowable error, the sample size increases with the confidence level. [10] Based on research by American market research expert Alan Dutka on the sample size required to meet various combinations of confidence levels and errors, and experiments validating the guidance on human body dimension measurements by scholar Han Ying, it is evident that the sample size for this experiment meets a confidence level of 90% and an allowable error of 4%, ensuring the required accuracy for the experiment's results.

(3) Experimental Tools

The experimental tools primarily include: laser rangefinders, electronic scales, measuring tapes, chairs, and body height measuring instruments.

3.3 Experiment Content: The Measurement Information of the Experimental Subjects was Recorded

(1) Basic Information of Experimental Subjects: This includes name (optional to choose real name/anonymous), age, gender, region, and collection items.

(2) Experimental Items:

Based on the categorization of anthropometric dimensions in the 1988 "Dimensions" standard and constrained by time and budget limitations, we primarily selected 21 anthropometric dimensions with high relevance for our study. These dimensions include:

height, weight, upper arm length, forearm length, thigh length, calf length, eye height in standing position, shoulder height, elbow height, hand function height, perineum height, tibial point height, sitting height in sitting position, eye height in sitting position, shoulder height in sitting position, elbow height in sitting position, thigh thickness in sitting position, knee height in sitting position, calf and foot height, hip-knee distance, and sitting lower limb length. Dimensional nodes are referenced in the diagram below, See Figure 2 below.

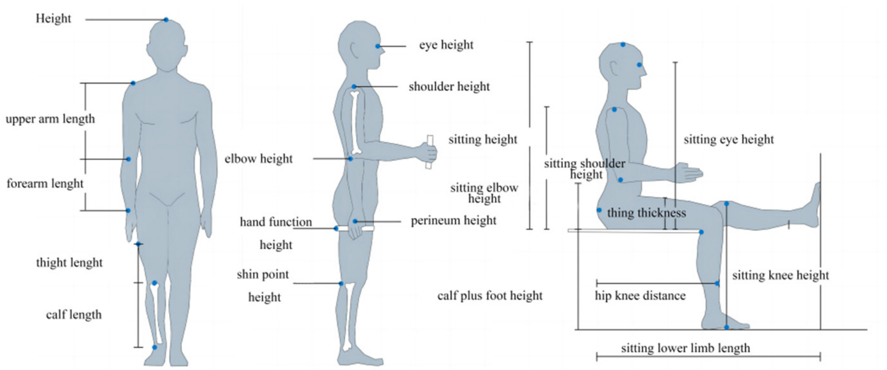

Fig. 2. Human size node diagram (Photo credit: author's own drawing)

3.4 Experimental Results: Statistical Analysis of the Measured Data

The regional distribution and proportion of experimental subjects are shown in Figure 3:

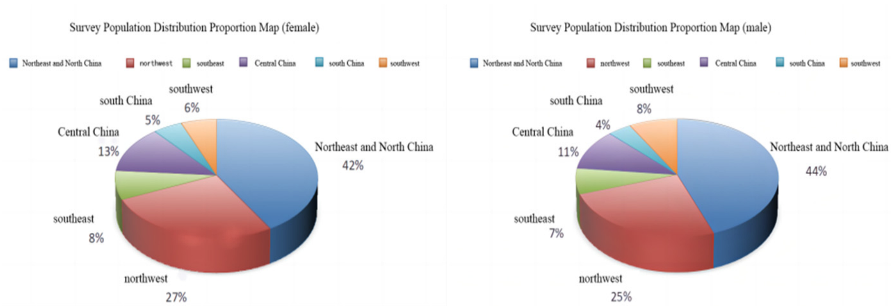

Fig. 3. Regional distribution map of survey population (Photo credit: author's own drawing)

Based on the measurement results, it is evident that the national average height and weight have both increased significantly. For males, the increase in height ranges from 24-57mm, while the increase in weight ranges from 7kg-58kg. Females, on the other hand, show an increase in height ranging from 0-65mm and an increase in weight ranging from 1kg-18kg. Excluding the highest and lowest values, the difference in height increase between males and females is negligible, but there is a significant difference in weight increase. Females tend to have significantly lower weight, which market research indicates is closely related to the prevailing aesthetic standard of thinness in today's society, As shown in Figure 4 below.

Among the measured male anthropometric dimensions, there is a significant difference between the values of the lowest and highest percentiles, which is directly related to the sample size. A larger sample size results in more balanced, clear, and consistent values, while a smaller sample size leads to more noticeable differences and less clarity in the patterns. Beyond the 50th percentile, many anthropometric dimensions begin to transition from negative to positive values. Elbow height, sitting height, sitting knee height, and sitting lower limb length show significant increases, but upper arm length remains consistently in a negative growth state. This may be attributed to the thickness of the clothing worn by the subjects during measurement. The measurement activities primarily took place outdoors and were conducted quarterly, which were greatly influenced by temperature fluctuations. Compared to males, females exhibit more balanced growth in anthropometric dimensions.

Age gropu / percentile / Measurement item	18-25 years old (female standing position)						
	1	5	10	50	90	95	99
Height	1464	1494	1524	1596	1678	1714	1774
weight	39	43	46	53	64	69	84
upper arm length	194	219	229	269	304	315	360
foream length	180	189	194	219	248	251	293
thigh length	339	349	359	389	459	469	479
thigh length	271	279	299	345	399	409	439
standing eye height	1143	1330	1363	1474	1548	1578	1649
standing shoulder height	1141	1189	1214	1304	1374	1411	1463
standing elbow height	845	905	924	989	1054	1077	1106
hand function	594	634	654	709	764	779	831
perineum height	619	668	679	744	809	830	869
tibial point height	314	350	370	442	484	507	554

Age gropu / percentile / Measurement item	18-25 years old (male standing position)						
	1	5	10	50	90	95	99
Height	1593	1633	1663	1743	1802	1813	1855
weight	50	55	57	69	84	96	136
upper arm length	240	253	258	295	328	333	347
foream length	188	203	208	248	278	285	298
thigh length	340	378	398	458	498	508	518
thigh length	294	303	318	383	428	433	455
standing eye height	1421	1513	1543	1628	1692	1707	1750
standing shoulder height	1213	1305	1323	1413	1493	1513	1547
standing elbow height	923	963	987	1053	1143	1165	1290
hand function	615	657	675	743	797	823	875
perineum height	694	718	733	803	872	883	910
tibial point height	383	405	415	473	518	533	558

Fig. 4. Partial measurements of human dimensions (Photo credit: author's own drawing)

3.5 Conclusion: The Size of Human Body is the Basis to Determine the Size of Indoor Space and Furniture Facilities

According to extensive statistical data and human factors research, it has been indicated that there exists an approximate proportional relationship among various static dimensions of the human body in normal adults. Once this proportional relationship is established, it becomes possible to approximate other static anthropometric dimensions based on the fundamental data of height. [11] Scholar Zhang Yunran pointed out in the study of human body shape similarity that for the same population, the constants of the human body vary with different sets of anthropometric dimensions and quantities. However, for identical sets of anthropometric dimensions and quantities, their constants should remain consistent. Through studies with different sample sizes, it has been ultimately demonstrated that constants exist in the interrelationships among anthropometric dimensions.[12]

Roebuck, in his research using measurement methods to study human body shape, discovered that as a statistical whole, certain proportional relationships among anthropometric dimensions are prominently observable. [13] Height, being a primary characteristic of the human body, largely determines the sizes of many other parts of the body. [14] Based on the aforementioned data and drawing from the derivation methods of scholar Han Ying regarding anthropometric dimensions, corrections were made to the 1988 "Dimensions" standard . The statistical results, as depicted in Figures 5, provide a partial set of anthropometric dimension data that can serve as a reference for the design of museum-like public spaces. These findings can contribute to the establishment of guidelines for indoor spatial dimensions and furniture dimensions.

Percentile measurement items		male (18-60 years old)						
		1	5	10	50	90	95	99
Standing	Height	1543+47	1583+47	1604+47	1678+47	1754+47	1775+47	1814+47
	eye height	1436+44	1474+44	1495+44	1568+44	1643+44	1664+44	1705+44
	shoulder height	1244+38	1281+38	1299+38	1367+38	1435+38	1455+38	1494+38
	elbow height	925+28	954+28	968+28	1024+28	1079+28	1096+28	1128+28
	hand founction height	656+20	680+20	693+20	741+20	787+20	801+20	828+20
	perineum height	701+21	728+21	741+21	790+21	840+21	856+21	887+21
	tibial point height	394+12	409+12	417+12	444+12	472+12	481+12	498+12
sitting posture	sitting height	836+25	858+25	870+25	908+25	947+25	958+25	979+25
	sitting eye height	729+22	749+22	761+22	798+22	836+22	847+22	868+22
	sitting shoulder height	539+16	557+16	566+16	598+16	631+16	641+16	659+16
	sitting elbow height	214+7	228+7	235+7	263+7	291+7	298+7	312+7
	sitting knee height	441+13	456+13	464+13	493+13	523+13	532+13	549+13
	calf plus foot height	372+11	383+11	389+11	413+11	439+11	448+11	463+11
	hip knee distance	499+15	515+15	524+15	554+15	585+15	595+15	613+15
	sitting lower limb length	892+27	921+27	937+27	992+27	1046+27	1063+27	1096+27

Percentile measurement items		female (18-60 years old)						
		1	5	10	50	90	95	99
Standing	Height	1449+20	1484+20	1503+20	1570+20	1640+20	1659+20	1697+20
	eye height	1337+19	1371+19	1388+19	1454+19	1522+19	1541+19	1579+19
	shoulder height	1166+16	1195+16	1211+16	1271+16	1333+16	1350+16	1385+16
	elbow height	837+12	899+12	913+12	960+12	1009+12	1023+12	1050+12
	hand founction height	630+9	650+9	662+9	704+9	746+9	757+9	778+9
	perineum height	648+9	673+9	686+9	732+9	779+9	792+9	819+9
	tibial point height	363+5	377+5	384+5	410+5	437+5	444+5	459+5
sitting posture	sitting height	789+11	809+11	819+11	855+11	891+11	901+11	920+11
	sitting eye height	678+9	695+9	704+9	739+9	773+9	783+9	803+9
	sitting shoulder height	504+7	518+7	526+7	556+7	585+7	594+7	609+7
	sitting elbow height	201+3	215+3	223+3	251+3	277+3	284+3	299+3
	sitting knee height	410+6	424+6	431+6	458+6	485+6	493+6	507+6
	calf plus foot height	331+5	342+5	350+5	382+5	399+5	405+5	417+5
	hip knee distance	481+7	495+7	502+7	529+7	561+7	570+7	587+7
	sitting lower limb length	826+11	851+11	865+11	912+11	960+11	975+11	1005+11

Fig. 5. Body size modification for 18-60 years old (Photo credit: author's own drawing)

4 The Reach Range Experiment of Wheelchair Users was Conducted Based on the Measurement Results

4.1 Objective: To Obtain the Human Dimensions of Wheelchair Users

In inclusive design, many dimensional specifications not only need to consider variations in human body dimensions but also need to take into account the impact of mobility aids used by people with disabilities on human body dimensions. The following set of simulated experiments primarily investigates the anthropometric dimensions of wheelchair users.

4.2 Methods: The Size and Reach of Human Body in Wheelchair were Measured by Sampling

Time and Location: October 2023, 18th Teaching Building, Tianjin University.

Experimental Subjects: Twelve students from Tianjin University were selected for the experiment, including one each from the 1st to 5th percentile, one from the 10th to 50th percentile, one from the 50th percentile, one from the 50th to 90th percentile, one from the 90th to 95th percentile, and one from the 95th to 99th percentile, with an equal distribution of six males and six females.

Experimental Tools: Wheelchair, laser rangefinder, flexible ruler, 100mmx100mm reference grid, camera, computer, etc. The size of the wheelchair used in the experiment is shown in Figure 6 below.

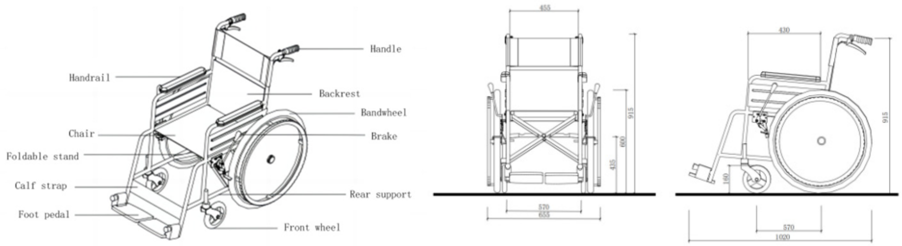

Fig. 6. Dimensions of the wheelchair (Photo credit: author's own drawing)

4.3 Experiment Content: The Data of the Reach of the Subjects in the Wheelchair Were Recorded

The experiment records three sets of data:

(1) Measurement of Subjects and Equipment

This involves measuring the dimensions of the subjects' various body parts, including height, arm length, shoulder width, etc., in a comfortable and relaxed state. It also includes measuring the dimensions of the wheelchair used, as shown in Figure 7.

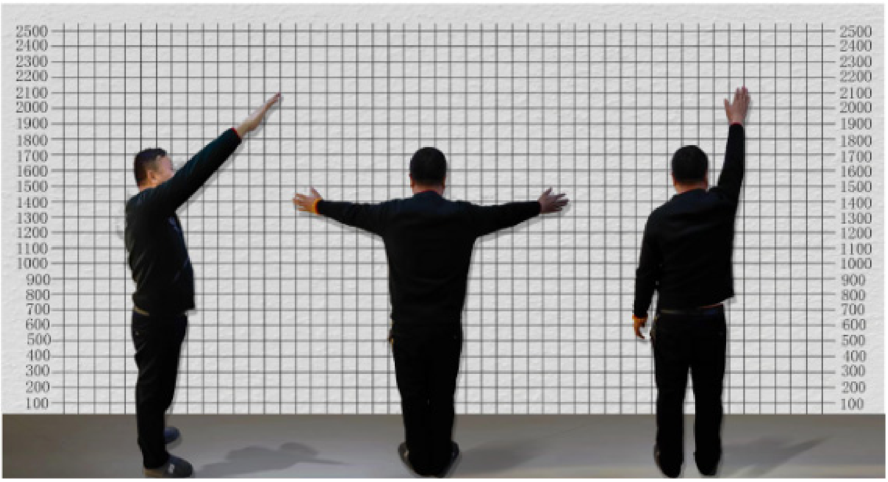

Fig. 7. Human size measurement diagram (Photo credit: author's own drawing)

(2) Measurement of Basic Movements and Reach Range

This constitutes the main aspect of the experiment, involving recording the subject's body dimensions and reach range from the front, side, and oblique angles, as depicted in Figure 8.

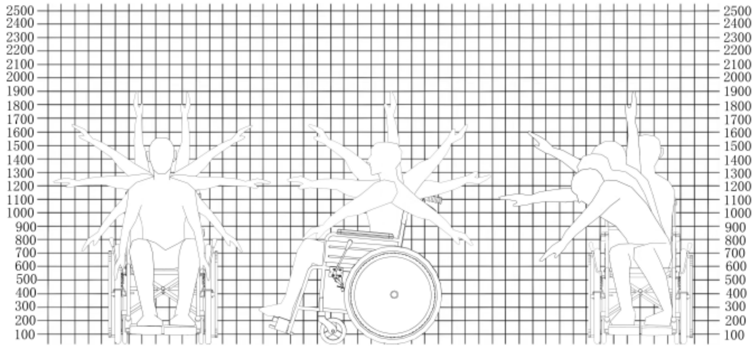

Fig. 8. Schematic diagram of the process line of touch range measurement (Photo credit: author's own drawing)

(3) Simulation Measurement of Museum Environment

Building upon the data acquired from (1) and (2), further simulations are conducted to assess the reach range for accessibility, navigation, and operation within museum-like public spaces. This aims to validate the relevant data and minimize potential errors.

4.4 Results: Statistical Analysis of Human Body Size and Reach Data when Riding Wheelchair

The experimental results are shown in the figure 9 below:

The date were measured when the subjects were in wheeichairs							
Measurement item		Male sample height					
		1640	1700	1750	1780	1820	1850
posture	Wheelchair height	1300	1335	1355	1344	1330	1364
	Wheelchair eyes tall	1200	1213	1210	1200	1260	1265
	Shoulder height in a wheelchair	1040	1042	1055	1050	1050	1043
	Elbow high in a wheelchair	680	690	700	724	710	685
	Wheelchair leg high	698	700	725	710	715	763
	Front width	460	485	505	454	465	510
	Side width	164	165	265	180	230	270
	The leght radius of front arm extension	710	750	755	720	825	820
	The leght radius of the side arm extension	665	710	675	675	778	800
	The maximum length radius of the side arm extension	670	680	665	675	700	790
Note: The maximum length radius of lateral arm extension refers to the ultimate function size obtained by adjusting the subject while sitting in a wheelchair							

The date were measured when the subjects were in wheeichairs							
Measurement item		Female sample height					
		1500	1550	1600	1650	1690	1720
posture	Wheelchair height	1245	1205	1320	1250	1285	1290
	Wheelchair eyes tall	1144	1114	1140	1170	1190	1170
	Shoulder height in a wheelchair	968	956	970	977	995	990
	Elbow high in a wheelchair	720	678	724	693	696	705
	Wheelchair leg high	620	655	650	685	710	735
	Front width	380	390	400	390	440	450
	Side width	160	220	205	205	203	235
	The leght radius of front arm extension	660	686	675	723	745	750
	The leght radius of the side arm extension	645	633	635	680	705	690
	The maximum length radius of the side arm extension	670	616	580	660	720	692
Note: The maximum length radius of lateral arm extension refers to the ultimate function size obtained by adjusting the subject while sitting in a wheelchair							

Statistical data of hand height of subjects in wheelchair								
Measure item hand height		Male sample height						
		1640	1700	1750	1780	1820	1850	
Frontal posture	Arm down 45 degrees	720	730	754	574	823	680	Side lift
	Arm lift	1010	1026	1055	970	1043	1120	
	Arms up 45 degrees	1380	1480	1400	1380	1392	1525	
	Arms up	1650	1740	1734	1690	1980	1828	
Lateral position	Arm forward and down 45 degrees	600	610	662	604	812	750	Front lift
	Arms flat in front of you	1020	1052	1030	1050	1037	1115	
	Arms up 45 degrees	1280	1510	1210	1430	1423	1450	
	Aems side up	1600	1622	1640	1667	1880	1710	
	Arms back up 45 degrees	1400	1491	1387	1419	1535	1410	Back lift
	Arms back flat	1010	1025	1000	1028	1057	1090	
	Arms back down 45 degrees	565	670	594	517	696	570	

Statistical data of hand height of subjects in wheelchair								
Measure item hand height		Female sample height						
		1500	1550	1600	1650	1690	1720	
Frontal posture	Arm down 45 degrees	650	680	700	750	693	707	Side lift
	Arm lift	920	890	960	940	970	996	
	Arms up 45 degrees	900	1382	1405	1266	1260	1322	
	Arms up	1634	1625	1615	1232	1665	1665	
Lateral position	Arm forward and down 45 degrees	463	775	680	685	610	600	Front lift
	Arms flat in front of you	960	965	990	690	990	980	
	Arms up 45 degrees	1300	1370	1325	1340	1400	1315	
	Aems side up	1520	1584	1420	1580	1480	1322	
	Arms back up 45 degrees	1302	1375	1500	1435	1370	1250	Back lift
	Arms back flat	830	944	920	972	1050	920	
	Arms back down 45 degrees	572	713	700	680	760	634	

Fig. 9. Simulated experimental measurement results (Photo credit: author's own drawing)

4.5 Conclusion: The Size and Reach Range of Human Body are Important Bases for the Design and Installation of Barrier-Free Facilities

The ultimate goal of the experiment is to understand the varying requirements of different accessibility facility designs concerning dimensions. For instance, the height of chairs is generally designed based on the average value of the 50th percentile, while considering both upper and lower population segments. Conversely, for safety passages, it is essential to ensure safe passage for all individuals, ideally designed according to the 99th percentile data. Conversely, for hazardous areas, to prevent access or touch, it is necessary to design based on the 1st percentile data, ensuring that the majority of individuals do not enter or touch. Based on this understanding of design, the rational utilization of measured human body dimensions and reach range data can provide crucial basis and reference for the design and installation of accessibility facilities:

When individuals are seated in a wheelchair, the total height from the ground to the top of the wheelchair ranges from 1205mm to 1354mm. This data is applicable for determining the minimum clear overhead space required for movement.

When individuals are seated in a wheelchair, the eye height ranges from 1144mm to 1265mm. This data is applicable for determining suitable heights for wheelchair users to view exhibits, accessibility signage, and display screens.

When individuals are seated in a wheelchair, the height from the ground to the legs ranges from 620mm to 763mm, with most footrest heights (dependent on wheelchair pedal height) around 500mm. This data is used to consider the lower clearance space required for furniture, facilities, and equipment used by wheelchair users.

When individuals are seated in a wheelchair in a frontal posture, the height of the elbows ranges from 678mm to 724mm. This data is used to determine the heights of counters, facility operation platforms, handrails, and Braille for wheelchair user convenience.

When individuals are seated in a wheelchair, the radius of arm extension length varies, with a range of 660mm to 825mm for front arm extension, 633mm to 800mm for lateral arm extension, and a maximum value of 580mm to 790mm for lateral arm extension.

5 Conclusion and Discussion

It is the responsibility of all design professionals to be aware of social trends and newly emerging social needs.[15] In the context of the trend towards humanized design and the continuous promotion of age-friendly accessible environment construction in China, research on human body dimensions in theory and practice plays a crucial role in enhancing relevant laws and regulations related to accessibility, establishing human body dimension standards more suited to the Chinese population, and providing design references and bases for museum-like public spaces. This research holds significant practical and pragmatic implications. Building upon the theoretical research, practical applications, and outcomes analysis of the 1988 Size Standard, this paper provides a comprehensive overview of the current status of accessibility environment construction and human body dimension research in China. Through active measurement and reach range experimentation, a dataset of 501 human body dimensions was collected, statistically analyzed, and used to formulate a Chinese human body dimension chart. Corrections were made to the 1988 Size Standard, and supplementary research was conducted to cover the age range of the 2023 Size Standard samples, resulting in adjustments and supplements to accessibility-related human body dimension data in China.

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