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Featured Article

Designing ergonomic toilets and bathrooms for older adults: A study on anthropometric dimensions and recommendations

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ABSTRACT

Aims: This study aimed to evaluate the ergonomic design of toilets and bathroom equipment for older adults using anthropometric measurements.
Design: This was a descriptive cross-sectional study.
Methods: Data were collected from 2,721 people aged ≥ 65 years in Turkey. Fourteen anthropometric measurements were evaluated. Body dimension characteristics were described using minimum, maximum, and arithmetic means and standard deviations and the 5th, 25th, 50th, 75th, and 95th percentiles.
Results: The measurements showed that companies generally do not design bathroom toilet equipment that is suitable for older adults.
Conclusion: This study provides advice to designers and manufacturers on how to adapt their products to the bathroom according to users' body characteristics in order to increase person-environment fit for older people.

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Introduction

Person-environment fit

The design of bathroom equipment should incorporate considerations of person-environment fit and body measurements to achieve optimal levels of use and functionality. The concept of person-environment fit pertains to the congruence between an individual's attributes and the attributes of their surrounding context.[1] When considering toilet and bathroom equipment, a desirable characteristic would involve the equipment being created in an ergonomic manner to accommodate various body measurements and movements of users, thus ensuring their comfort, safety, and usability. The dimensions of the human body are important for attaining a suitable match between individuals and their surrounding environment, particularly in relation to toilets and bathroom equipment.[2] Ensuring optimal alignment between individuals and their surroundings in the context of toilets and bathroom equipment is crucial for enhancing user contentment and usability. The pleasure of users is strongly correlated with the usability of the equipment, and a suitable match enhances both the simplicity of use and functionality.[3,4] Anthropometric measurements, including parameters such as height, weight, and body proportion, offer significant information regarding the design prerequisites of the equipment. Designers can develop equipment that serves a diverse variety of users, thereby fostering inclusivity and accessibility through the careful consideration of body measurements. Optimal comfort, safety, and utility can be attained by aligning the proportions of equipment with the body dimensions of the users.[5,6]

Falls

The alignment between an individual and their surrounding environment plays a pivotal role in safeguarding their well-being, with a specific emphasis on mitigating the occurrence of accidents and falls within the bathroom setting, especially among older persons who may experience functional impairments.[1,2,4,7] Falls are a significant threat for older adults. In society, people over 65 years of age fall at least once a year, and people over the age of 85 fall at least twice a year.[8,9] Falling can cause bone fractures, soft tissue injury, impaired mobility, long-term disability, loss of independence, and even

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death.[10] It causes psychological distress, embarrassment, persistent fear of falling, anxiety, and a loss of trust. It also has social consequences for older people, such as care needs and economic burdens.[11-14] In general, the products and equipment in the toilet and bathroom suitable for the body characteristics of adults are inadequate and do not meet the needs of older people.[15,16] Designers can mitigate the likelihood of accidents by considering various body measurements, such as the reach and mobility of individuals, while creating equipment. For that, crucial to arrange grab bars at suitable heights and distances to provide the necessary support and stability during transfers and moves.[17]

Therefore, anthropometric measurements are of great importance in designing the ergonomic living environment of older adults to ensure harmony with the environment and improve their lifestyle.[18,19] Based on this, anthropometric measurements of the older population were collected and assessed for design purposes. The minimum, maximum, mean, and percentage values of the body dimensions applicable to toilet and bathroom equipment were provided for the design of ergonomic toilets and bathroom environments for older people. Some products in the market were evaluated for their suitability, and recommendations were offered to designers.

Material and method

Study design and sample

This was a descriptive cross-sectional study. A nationwide survey was conducted within the scope of the study, between 2015 and 2017. Based on the population data of the Turkish Statistical Institute, the sample size was calculated to be 2721 individuals, and stratified simple random sampling was applied considering each geographical region of Turkey as a stratum and 26 provinces as sampling units.[20]

Procedure and measures

Anthropometric measurements were taken from 1530 female and 1191 male participants using the techniques described in the Anthropometric Standardization Reference Manual (ASRM).[21] Fourteen anthropometric measurements were evaluated (Figs. 1. and 2). These are (1) weight, (2) height, (3) shoulder height, (4) total lower limb length, (5) shoulder–fingertip length, (6) elbow–fingertip length, (7) sitting height, (8) sitting shoulder height, (9) sitting elbow height,

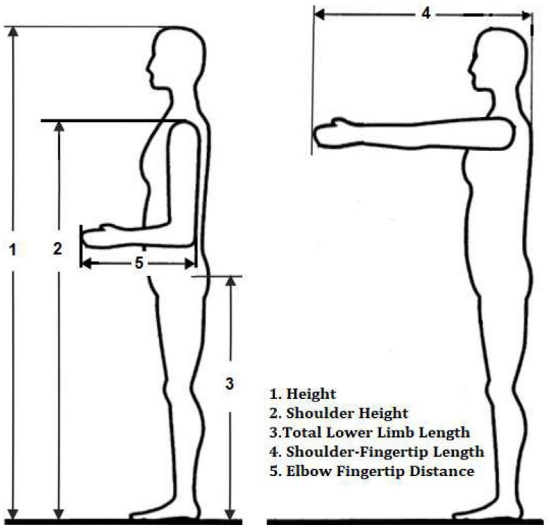


Fig. 1. Anthropometric measurements in standing positions

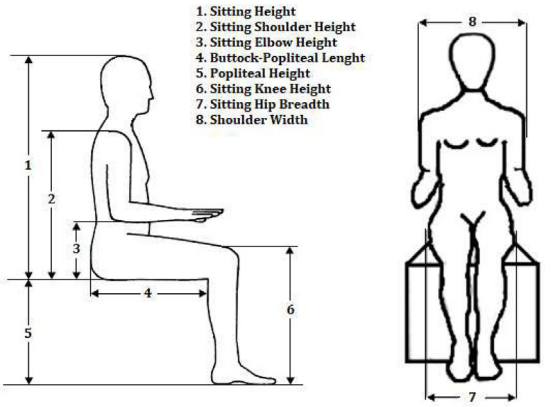


Fig. 2. Anthropometric measurements in sitting position

(10) sitting hip breadth, (11) shoulder width, (12) buttock–popliteal length, (13) popliteal height, and (14) sitting knee height.

To determine the suitability of the toilet and bathroom equipment available in the market, the product catalogues of six companies were comparatively examined. Company names were kept anonymous and labelled as A, B, C, D, E, and F for ethical reasons. Anthropometric measurements were compared to the dimensions used by companies in their products.

Data analysis

Body dimension characteristics were described using minimum, maximum, and arithmetic means and standard deviations, and the 5^{th}, 25^{th}, 50^{th}, 75^{th}, and 95^{th} percentiles were calculated using IBM SPSS Statistics V22.0.

Results

Anthropometric characteristics of older adults

Tables 1 and 2 show the minimum, maximum, mean, standard deviation (SD) and percentiles of anthropometric dimensions applicable to the design of toilets and bathroom equipment for females and males. Table 3 summarizes the anthropometric dimensions corresponding to toilet and bathroom equipment and their associations with body dimensions. Six products in the market were assessed, and their appropriateness for body dimensions in older individuals is presented in Table 4.

Evaluation of toilet and bathroom products in the market

As shown in Table 4, we evaluated the appropriateness of toilet and bathroom products for older individuals, based on the measures provided by the companies. The products of companies A, B, and C were not suitable for the height (1774 mm) of accessing the top of the wash basin cabinets or for easy access to the workbench. Product A was suitable for the buttock popliteal length, whereas products B and C were unsuitable. Companies A, B, and C were unsuitable for measuring the shoulder-fingertip length (647 mm) to access the forward endpoint of the cabinets.

Product A was suitable for height (1394 mm-1774 mm) at the top of the tall cabinets, whereas products B and C were not. It was found that the products of companies A, B, and C were suitable for shoulder-fingertip length (647 mm) measurements to access the forward endpoint of the cabinets.

Product A was suitable for a height (1774 mm) for the proper viewing angle of the bathroom mirror, but products B and C were

Table 1
Descriptive statistics for measured anthropometric dimensions (kg-mm) for female individuals over 65 years old

Anthropometric dimensions	Female									
	n	Min.	Max.	Mean	SD	Percentiles				
						5	25	50	75	95
Weight	1530	31	140	71	15,23	47	60	69	80	97
Height	1530	1238	1691	1489	68,65	1369	1445	1491	1535	1600
Shoulder height	1530	111	1523	1245	74,41	1125	1206	1250	1291	1352
Total lower limb length	1530	641	1273	790	60,13	703	751	782	823	892
Shoulder-Fingertip Length	1530	462	932	729	47,89	647	700	732	762	798
Elbow-Fingertip Length	1530	236	513	397	26,74	356	383	398	413	433
Sitting Height	1530	584	933	773	51,88	683	740	775	810	854
Sitting Shoulder Height	1530	336	738	534	45,06	458	508	535	562	603
Sitting Elbow Height	1529	91	725	164	37,83	121	141	157	183	228
Sitting Hip Breadth	1530	178	523	344	35,74	286	321	343	368	403
Shoulder Width	1530	218	480	372	30,29	326	352	372	390	422
Buttock-Popliteal Length	1528	362	580	461	31,48	408	440	463	476	512
Popliteal Height	1527	280	543	418	25,21	380	403	418	433	453
Sitting Knee Height	1527	346	603	507	29,59	457	491	510	526	551

Table 2
Descriptive statistics for measured anthropometric dimensions (kg-mm) for male individuals over 65 years old

Anthropometric dimensions	Male									
	n	Min.	Max.	Mean	SD	Percentiles				
						5	25	50	75	95
Weight	1191	38	142	75	14,83	52	65	75	85	100
Height	1191	1360	1884	1639	69,72	1524	1595	1640	1681	1749
Shoulder Height	1191	1119	1970	1387	69,91	1280	1344	1387	1432	1495
Total Lower Limb Length	1191	663	1307	873	59,45	773	833	871	911	968
Shoulder-Fingertip Length	1191	585	940	808	46,69	728	781	808	838	883
Elbow-Fingertip Length	1191	276	548	434	25,38	397	422	436	451	470
Sitting Height	1191	650	963	843	49,92	752	811	848	880	921
Sitting Shoulder Height	1191	440	753	591	44,16	513	562	592	621	661
Sitting Elbow Height	1191	93	337	180	38,02	130	151	173	203	251
Sitting Hip Breadth	1191	213	515	341	30,73	292	321	340	360	391
Shoulder Width	1191	233	503	407	28,73	363	388	408	425	454
Buttock-Popliteal Length	1191	370	585	478	30,44	428	462	476	501	527
Popliteal Height	1191	201	551	440	25,15	403	427	440	453	480
Sitting Knee Height	1191	421	623	540	27,37	497	523	540	557	583

In the decimal parts of the measured values in Tables 1 and 2, the 0-49 number range was left constant, the 50-99 number range was rounded off, and a +1 number was added to the full part of the measured value. Thus, the measured values were expressed as integer values by discarding decimals.

not. In addition, the products of companies A, B, and C were suitable for the total lower-limb length (838 mm).

None of the products (A, B, D, E, F) was appropriate in terms of total lower limb length (728 mm) for easy access of the sinks to the counter. All the companies (A, B, D, E, and F) produced suitable goods in terms of shoulder-fingertip length (647 mm) for access to the forward endpoint of the wash basins.

The products of all companies (A, C, D, E, and F) were suitable in terms of the total lower limb length (968 mm) for easy gripping of the grab bars as a standing support. Companies A, E, and F produced suitable goods to reach the forward endpoint in terms of shoulder-fingertip length (647 mm), whereas companies C and D did not.

Companies A, C, D, E, and F had goods suitable for the width of the toilet seats for sitting hip breadth (403 mm), whereas Company B did not. Considering the depth of the seat, companies A, B, E, and F were suitable for measuring the popliteal length of the buttock (512 mm), whereas companies C and D were unsuitable. Regarding the height between the toilet bowl and the floor, companies A and C had a suitable design in terms of popliteal height (405 mm), whereas companies B, D, E, and F did not.

Companies A and C had products suitable for the width of the shower seat in terms of sitting hip breadth (403 mm), whereas Companies D and E did not. All companies (A, C, D, E, F) were suitable for measuring the buttock popliteal length (512 mm) for the depth of the seat. For the height between the toilet bowl and floor, the products of Company C were suitable in terms of popliteal height (405 mm), but A, D, and E were not.

Discussion

This descriptive study aimed to evaluate the ergonomic design of toilets and bathroom equipment for older adults, using anthropometric measurements. Anthropometric measurements of older people play a crucial role in the design of bathroom and toilet equipment and in ensuring person-environment fit. These measurements provide valuable insights into the physical characteristics and limitations of older individuals, allowing designers to create products tailored to their specific needs and promote safety and independence.[24,25]

The design of toilets and bathroom fixtures should consider the range of motion and reach of the users and their sitting and standing postures. By considering anthropometric data, designers can ensure that toilets are at an appropriate height and that grab bars are correctly positioned to provide support and stability.[5] In this study, five out of six products had sufficient toilet seat breadth based on Sitting Hip Breadth measurement. When the seating depth is based on buttock–popliteal length measurement, the four products have

Table 3
Anthropometric Dimensions Related to the Design of Toilet-Bathroom Equipment and Their Relationship with Body Dimensions

Anthropometric dimensions	Fixture and fittings in toilets and bathrooms	Relationship to body dimensions
Weight	Toilet seat (closet), shower seat	It is the value specified for precautionary purposes, considering the risk of an accident during the use of equipment.
Height	Washbasin cabinets	It is related to the length of the upper limit of the upper modules of the washbasin cabinets (the upper limit should be 95th percentile male).
	Tall cabinets	It is related to the distance at which tall cabinets are mounted and the floor (5th percentile female - 95th percentile male).
	Bathroom mirror	The distance between the top of the bathroom mirrors and the floor is related (95th percentile male).
	Showerhead	It is related to the mounting distance of the shower head and the floor (upper limit 95th percentile male +100 mm).
Shoulder Height	Handlebars	The distance between the mounting location of the grab bar and the floor is related (upper limit 95th percentile male).
Total Lower Limb Length	Washbasin, Washbasin cabinets	It is related to the distance between the stall of the washbasin and the floor (5th percentile female).
	Handlebars	It is related to the distance between the handlebars and the floor 95th percentile male should be taken as the lower limit when using this measure.
	Bathroom mirror	The distance between the lowest point of the bathroom mirrors and the floor is related (must be 5th percentile female).
	Water regulator, Soap dispenser	The distance between the installation location of both the water regulator and soap dispenser equipment in the shower area and the floor is related (5th percentile female + 100 mm).
Shoulder-Fingertip Length	Washbasin	It is related to the distance between the individual and the water faucet in washbasins.
	Handlebars	The distance of handlebars in parallel with the arms is related.
	Washbasin cabinets	In washbasin cabinets, the parallel extension distance of the counter and arms is related.
	Tall cabinets	It is related to the parallel extension distance of the arms, depending on the use of tall cabinets.
	5th percentile female should be taken as the lower limit when using the measure of shoulder-fingertip length.	
Elbow-Fingertip Length	Washbasin	The mounting distance of the washbasins and the faucet is related to each other (5th percentile female).
Sitting Height	Toilet seat (closet), shower seat	It is a suggested measure that will help older people to have the correct posture while using the toilet and shower seat. (Upper limit 95th percentile male).
Sitting Shoulder Height	Toilet seat (closet) bidet faucet	The distance between the bidet faucet on the edge of the toilet bowl and the floor is related (5th percentile female).
Sitting Elbow Height	Toilet seat (closet), shower seat, handlebars	It is a suggested measure that will benefit the equipment in the design and use of toilet bowls, shower seats and grab bars (5th percentile female).
Sitting Hip Breadth	Toilet seat (closet), shower seat	The width of the toilet and shower seat seating surfaces is related to being convenient to use (95th percentile female).
Shoulder width	Shower area	It is related to the width of the shower area (minimum 95th percentile male).
Buttock-Popliteal Length	Toilet seat (closet), shower seat	It is related to the position of the hip and knee joints to maintain the correct posture of the body during the use of toilet seat and shower seat (95th percentile female).
Popliteal Height	Toilet seat (closet), shower seat	During the use of the toilet and shower seats; knee joints, equipment, and ground clearance are related (95th percentile female).
Sitting Knee Height	Washbasin, Toilet seat (closet)	It is associated with the minimum space between the sink and the floor (95th percentile male). The suitable toilet seat height for older people is equivalent to the 95th percentile of men and women's sitting knee height.

This table was adapted from a study entitled 'Application of Anthropometric Measures to Space Design'.[22]

sufficient suitability. For toilet seat height, only two products had sufficient suitability based on the Popliteal Height. The two products were suitable for the width of the shower seat in terms of sitting hip breadth, whereas two products weren't. Five products were suitable for buttock popliteal length for the depth of the shower seat. For the height between the shower seat bowl and floor, one product suitable in terms of popliteal height, but three products were not. Similarly, Dasgupta et al. argued that it is important for toilet seats to accommodate persons with different hip breadth and knee height measures.[26] A study by Tharbthong et al. focused on determining a suitable toilet seat height for older Thai people.[25] The researchers used anthropometric measurements of 342 older individuals to design a mock-up toilet with a specified seat width based on the 95th percentile of hip breadth. They also highlighted the importance of considering anthropometric measurements in determining the appropriate dimensions of toilet seats to ensure comfort and ease of use for older individuals.[25] Afifi et al. drew attention to similar points in their systematic review of geriatric bathroom designs.[27]

In addition to seats, anthropometric measurements can inform the design of other bathrooms and toilet equipment. For example, lower extremity strength, which is related to activities such as bathing, mobility, and toileting, tends to decline earlier in older people than upper-extremity strength.[28] This suggests that bathroom and toilet equipment should be designed to accommodate the potential loss of lower extremity strength in older individuals, such as providing grab bars or handrails to assist with balance and mobility. In this study, all six products were suitable in terms of the total lower limb length for easy gripping of the grab bars as standing support. Three products were suitable for reaching the forward endpoint in terms of shoulder-fingertip length, whereas two products were not. Similarly, it has been suggested that the optimal handrail height for older adults falls within a specific range, and deviations from this range may affect user preferences and safety.[27,29] Gitlin et al. conducted a randomised trial to reduce functional difficulties in older adults and found that the design of bathrooms and toilet equipment should consider the reach and grip strength of older individuals.[30]

None of the products were suitable for accessing the top of the sink cabinets. Three products were unsuitable for shoulder fingertip length to access the forward endpoint of the cabinets. One product was suitable for the height at the top of the tall cabinets, whereas two products were not. The three products were suitable for shoulder fingertip length measurements to assess the forward endpoint of the cabinets. One product was suitable as a height for the proper viewing angle of the bathroom mirror, but the other three products were not. In addition, the three products were suitable for the total lower limb length. None of the products were appropriate in terms of total lower limb length for easy access of the sinks to the counter. All products are suitable goods in terms of shoulder-fingertip length for access to the forward endpoint of wash basins. Several studies also suggest that the use of accurate anthropometric data is essential for customizing the height and depth of countertops and sinks to ensure that they are accessible and functional to individuals of different statures.[31,32]

Table 4
Comparison of the measures used in the toilet-bathroom equipment and the anthropometric measurements

Measure used (Companies that have specified product design dimensions)	**Product used (mm)**		**Appropriate**	**Not suitable**
Height (A, B, C)	Sink Cabinets (95^{th} percentile male)	1774		A, B, C
	Tall Cabinets (5^{th} percentile female – 95^{th} percentile male)	1394-1774	A	B, C
	Bathroom Mirror (95^{th} percentile male)	1774	A	B, C
Total Lower Limb Length (A, B, C, D, E, F)	Bathroom Mirror (5^{th} percentile female +100)	838	A, B, C	
	Sink (5^{th} percentile female)	728		A, B, D, E, F
	Sink Cabinets (5^{th} percentile female)		A	B, C
	Holding Bar (95^{th} percentile female)	968	A, C, D, E, F	
Shoulder-Fingertip Length (A, B, C, D, E, F)	Sink (5^{th} percentile female)	647	A, B, D, E, F	
	Washbasins (5^{th} percentile female)		A, B, D, E, F	
	Holding Bar (5^{th} percentile female)		A, E, F	C, D
	Sink Cabinets (5^{th} percentile female)			A, B, C
	Tall Cabinets (5^{th} percentile female)		A, B, C	
Buttock-Popliteal Length (A, B, C, D, E, F)	Toilet seat (95^{th} percentile female)	512	A, B, E, F	C, D
	Shower Seat (5^{th} percentile female)		A, C, D, E, F	
Popliteal Height (A, B, C, D, E, F)	Toilet seat (5^{th} percentile female)	405	A, C	B, D, E, F
	Shower Seat (5^{th} percentile female)		C	A, D, E
Sitting Hip Breadth (A, B, C, D, E, F, G)	Toilet seat (5^{th} percentile female)	403	A, C, D, E, F	B
	Shower Seat (5^{th} percentile female)		A, C	D, E

25 mm shoe and slipper height are added to all measurement units showing height.

This table has been adapted from a study entitled 'Sustainable Product Design for Everyone: Braun Plug Design Competition Analysis'.[23]

Recommendation for designing basic fixtures and fittings of toilets and bathrooms for older people

The most basic toilets and bathroom fittings include wash basins, wash basin cabinets, tall cabinets, mirrors, water faucets, closets, shower seats, and handlebars.

The height of the wash basin should be arranged corresponding to the 5^{th} percentile for females. A single-lever water faucet should be used because it requires less force for the operation. It is located approximately 5 cm above the rim of the basin. The optimum water source height was estimated as the standing elbow height of the 5^{th} percentile female patient. The horizontal distance between the edge of the sink and the water tap should be approximately equal to the elbow-fingertip distance of the 5^{th} percentile for females. The use of a shorter horizontal distance prevented excessive stretching. The mirror should be placed above the sink for viewing, and its position should accommodate easy access for both short females (elbow height) and taller males. The minimum space in front of the sink area corresponded to the squatting range of the 95^{th} percentile male which was equal to the sitting height.

The toilet area included a closet, a handrail, and a tissue holder. The toilet seat height should be the same as the chair seat height, which is set at the sitting popliteal height of the 5^{th} percentile for females. Flush control should be accessible while sitting and at the sitting shoulder height of the 5^{th} percentile for females. The water hose should be located on the right-hand side and the single-lever water control should be at the sitting elbow height of the 5^{th} percentile female.

A horizontal handrail in the toilet area is useful for providing support while sitting. Its height should be around the sitting elbow height of the 5^{th} percentile females. The diameter of the horizontal handrail and the gap between it and the vertical wall are 3.81 cm.

The height of the wipe holder should be approximately the same as that of the horizontal handrail (i.e. at elbow height when sitting). A vertical handrail is useful for standing after toilet use. The height should be between the female minimum sitting height and the maximum standing shoulder height of the male.

The minimum width of the shower area should cover the elbow room required by the 95^{th} percentile of males. The optimum height for a fixed showerhead should be sufficiently high to accommodate the 95^{th} percentile male stature height, including the clearance (10 cm). An adjustable showerhead should be within the range of both the sitting height of the 5^{th} percentile female and the stature height, with clearance from the 95^{th} percentile male. A single water controller should be in line with the showerhead, and its height should be at the standing elbow height of the 5^{th} percentile females. The vertical handrail should be placed in the shower area for balancing while bathing, with the minimum height at the elbow height of the 5^{th} percentile male and the maximum height at the shoulder height of the 95^{th} percentile male. The horizontal handrail height should be in the 5^{th} percentile of the female elbow. The optional seat in the shower area should be the popliteal height of the 5^{th} percentile female, with a seat width of the 95^{th} percentile female sitting hip breadth and a seat depth of the 95^{th} percentile female buttock popliteal length. Temporary storage for toiletries should be located at the shoulder height of the 5^{th} percentile for females. The soap dish should be

within the reach of shorter persons at an elbow height of the 5th percentile for females.

These measurements provide valuable insights into the physical dimensions and characteristics of the older population, which can inform the design of suitable and accessible equipment and promote independence and safety. By considering anthropometric measurements, ergonomic factors, and the specific needs of older individuals, designers can create bathrooms and toilet equipment that enhance the well-being and quality of life of older people.

Conclusion

In conclusion, anthropometric measurements are a critical consideration in the design of bathroom and toilet equipment. By incorporating anthropometric data into the design process, designers can create equipment that accommodates a diverse range of users, enhances comfort and safety, and minimises the risk of musculoskeletal disorders and accidents. However, it is important to recognise that anthropometric measurements should be considered in conjunction with other factors, such as the specific needs of user groups and the overall design of the environment, to ensure a comprehensive person-environment fit. The authors recognise that anthropometric measures are a step toward an essential approach that person-environment fit generates to support safe aging.

Declaration of Competing Interest

The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

Data Access Statement

Research data supporting this publication are available from the TR Index repository at https://search.trdizin.gov.tr/en/yayin/detay/620343/anadolu-yaslilarinin-antropometrik-boyutlari.

Ethical Consideration

Cumhuriyet University Ethics Committee gave ethics approval with the number 2014 03/15. Written and verbal informed consent was obtained from each participant before participation in the study.

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