J. Human Ergol., **35**: 11-19, 2006

EXPERIMENTAL STUDY ON THE GRIP AND HOLD STRENGTH FOR STANCHIONS AND HANDRAILS IN BUSES

TERUO UETAKE* AND MASAHIRO SHIMODA

Research Institute of Symbiotic Science and Technology
Tokyo University of Agriculture and Technology
3-5-8 Saiwai, Fuchu, Tokyo 183-8509, Japan
**E-mail: uetake@cc.tuat.ac.jp*

The purpose of this study was to investigate the effective use of stanchions and handrails in buses. We constructed experimental equipment resembling bus stanchions and handrails and examined the grip and hold strength exerted when used. The total number of subjects was 80: 30 elderly and 19 young males, and 22 elderly and 9 young females.
The experimental equipment comprised four parts: a handle part to imitate safety devices in buses such as stanchions, handrails, and straps, which was pulled by a winch at a constant speed; and a load cell wired with an analyzing processor, which output the strength exerted. The handle part was designed to measure grip and hold strengths against pulling forces in three directions, that is, forward, in the direction of the back of the hand, and in the direction of the palm.
The subjects were asked to grasp the handle part against a pulling force. The maximum grip and hold strengths were recorded and analyzed. The strengths when pulled forward were the largest independent of the sex and age of the subjects. The results indicate that standing bus passengers should grip the fixtures, such as a stanchion, with their right hand when they are standing on the right side in a bus facing the windows.
Key words: grip and hold strength; stanchion; handrail; bus

INTRODUCTION

Japan represents one of the most aged societies in the world. It is expected that in the near future, one in three individuals will be elderly or above age 65. Improvements are thus necessary in the infrastructure required for an aged society before the situation becomes serious. There are many requirements that need to be addressed to meet the needs of the elderly. Safe transportation systems are particularly important, because mobility is necessary to maintain the quality of life for the elderly. In an aged society, transport by bus plays a very important role. Bus transportation systems are indispensable for the mobility and flexibility of the elderly, as demonstrated by the increasing use of low-floor and non-step buses for the convenience of the elderly.

Unfortunately, about 3000 bus accidents occur each year in Japan (Ministry of Land, Infrastructure and Transport, 2004), and many elderly people are injured. It is necessary to clarify the causes of these accidents from various viewpoints and to undertake effective actions based on the facts ascertained.

Generally, the muscle strength of elderly people undergoes a steady decline (Laboratory of Physical Education, Tokyo Metropolitan University, 1989). We postulated that this decrease in muscle strength would have a close relationship with the injuries occurring on buses, especially when the elderly have to stand and to grasp nearby fixtures. We thus focused our attention on the grip and hold strength of the elderly.

Numerous studies have been conducted on the various aspects of grip strength. It is well known

Received for publication October 10, 2006.

that the grip strength of a man correlates with his physical fitness, so there are many reports on grip strength from the point of view of fitness training or rehabilitation programs. For example, Luna-Heredia *et al*. (2004) found that grip strength in healthy individuals was correlated negatively with age and positively with height. Kenjle *et al*. (2005) recommended that the grip strength test should be added to the assessment of nutrition. Van-Huevelen *et al*. (2000) concluded that grip strength, walking endurance, and manual dexterity would predict disability in elderly individuals. Much attention has also been given to grip strength in the field of industrial and medical robotics (Ikeda et al., 2004; Ueda et al., 2005; Bang et al., 2005)

Our research aims to determine the most effective way to grip and hold a stanchion or a handrail when standing in a bus. This experimental study was the first step. We constructed experimental equipment resembling a bus stanchion or handrail and examined the strength exerted when using it.

METHODS

Subjects: The total number of subjects was 80: 30 elderly and 19 young males, and 22 elderly and 9 young females. All the subjects were healthy and had no serious clinical histories. All of them, except two elderly and four young male subjects, were right-handed. In all the subjects, the handedness side was used for the measurement of grip strength (Table 1). The study was approved by the Ethical Committee for experiments involving human subjects at the Tokyo University of Agriculture and Technology. All the subjects provided written informed consent.

Table 1. Mean and SD of age, stature, weight, and grip strength in the subjects.

Group	N	Age (years)	Stature (cm)	Weight (kg)	Grip strength (kg)
EM	30	73.8±5.09	161.3±6.78	59.3±6.33	36.7±6.63
EF	22	72.5±5.80	151.5±5.11	50.8±5.76	24.0±4.78
YM	19	20.6±1.39	173.0±5.93	65.6±5.11	50.5±6.64
YF	9	18.8±1.09	160.3±8.79	53.9±9.81	33.9±6.06

EM:Elder male, EF:Elder female, YM:Young male, YF:Young female

Experimental equipment and procedures: The experimental equipment comprised four parts: a handle part (Figure 1-a), imitating the safety devices used in buses such as props, handrails, and straps, which was pulled by a winch (Model No.2001; Shin Jiuh Diing Co. Ltd; Figure 1-b) at a constant speed of 3 mm per second, and a load cell (Model No. 12695; Takei Kiki Kogyo Co. Ltd; Figure 1-c) wired with an analyzing processor (Model No. 5710a; Takei Kiki Kogyo Co. Ltd; Figure 1-d), which recorded the strength exerted.

Under experimental conditions in a laboratory, it is necessary to simplify a subject's posture as much as possible. Therefore, when the experimental conditions such as a subject’s position were decided, we took into account the following points based on pre-observations about not only the bus passengers but also the bus structures. That is, in general a stanchion and a handrail in a bus are set up vertically; almost all standing bus passengers are squarely located for the traveling direction and hold a stanchion or a handrail in front of them or on the same side as the using hand; their wrist joints are in a neutral position, not extended or flexed and not adducted or abducted.

The handle part was designed to measure the strength exerted against pulling forces in three directions. However, only one direction was chosen when involving a strap because when a strap is used in a bus, the axis of the forearm roughly agrees with that of the strap. Subjects would have to change their sitting position to alter the pulling direction. In this study, two different caliber steel pipes, 33 mm and 42 mm in diameter, were used as the handle part to imitate a stanchion. A training strap was used to imitate the straps on a bus, and the handle part was designed to be exchanged easily if necessary. According to the subject’s sitting height, a chair was adjusted so that their elbow level could become the same and the subjects were asked to sit on the chair while the experimental procedures were carried out.

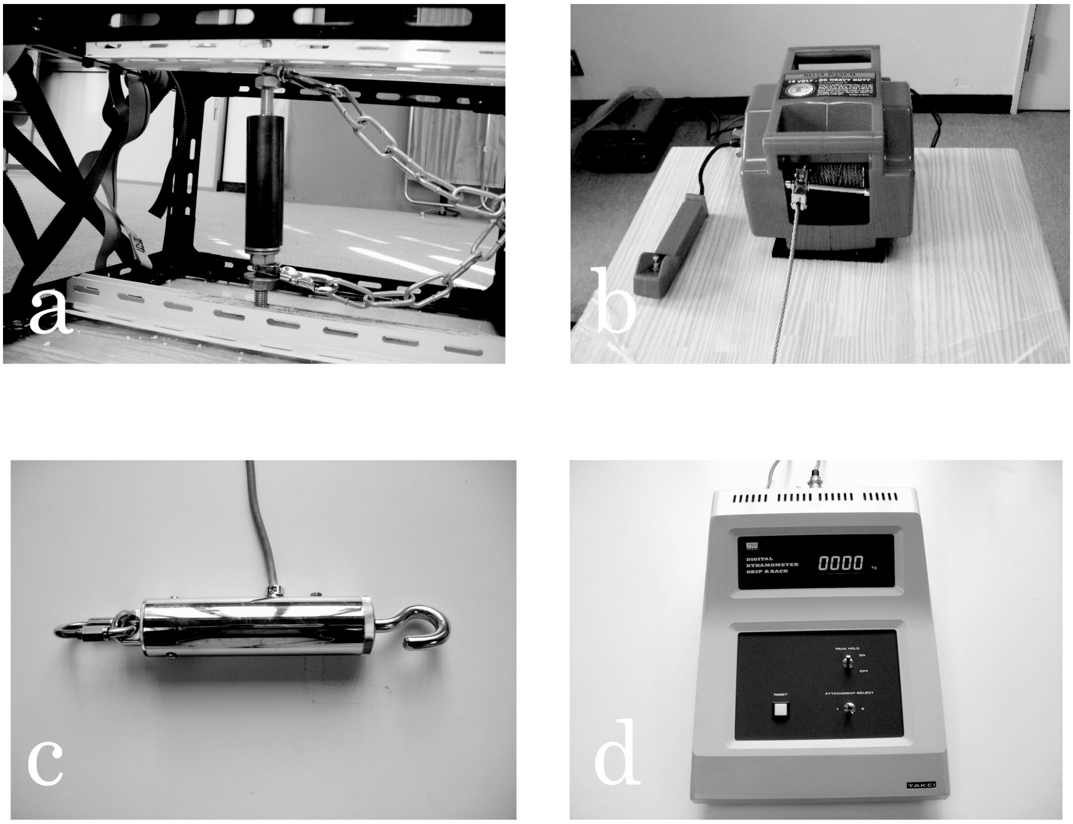

Fig. 1. Experimental equipment used in this study. a; the handle part imitating safety devices such as props, and handrails that was set between guide rails, but the training strap was not fixed with guide rails, b; the winch for winding the steel wire at a constant speed of 3 mm per second, c; the load cell wired with an analyzing processor, d; the analyzing processor which calculates and displays the strength.

The subjects were informed of the experimental procedures and asked to cease from gripping the handle part before they had any pain in their wrist during the experimental measurements. Attributes such as age, height, weight, hand length, and hand dominance side were recorded prior to all the experimental tasks. Then, according to the protocol issued by the Ministry of Education, Culture, Sports, Science and Technology, grip strength was measured with a hand dynamometer. It was measured twice for three different handle parts, two different caliber steel pipes, and a training strap. Continuous measurements with the same subject were avoided to prevent muscle fatigue.

As mentioned above, a winch pulled the handle part. There were three pulling directions; forward, in the direction of the back of the hand, and in the direction of the palm. These pulling directions could be changed by altering the subject's sitting position (Figure 2).

To pull the handle part in the direction of the back of the hand (Figure 2-c) or the palm of the hand (Figure 2-d), subjects were asked to place their upper limb at about 90° to the pulling direction, and their wrist and elbow were fixed to the experimental equipment with a soft belt and bandage. To pull the handle part in the forward direction (Figure 2-a, 2-b), the subjects were asked to place their upper limb in the direction of pull and to position their *Artic. cubiti* at about 90°; their elbow and shoulder were fixed in the same way as above. By this procedure, the effects of muscles around the shoulder and the muscle of the arm were eliminated as much as possible so that the strength of the

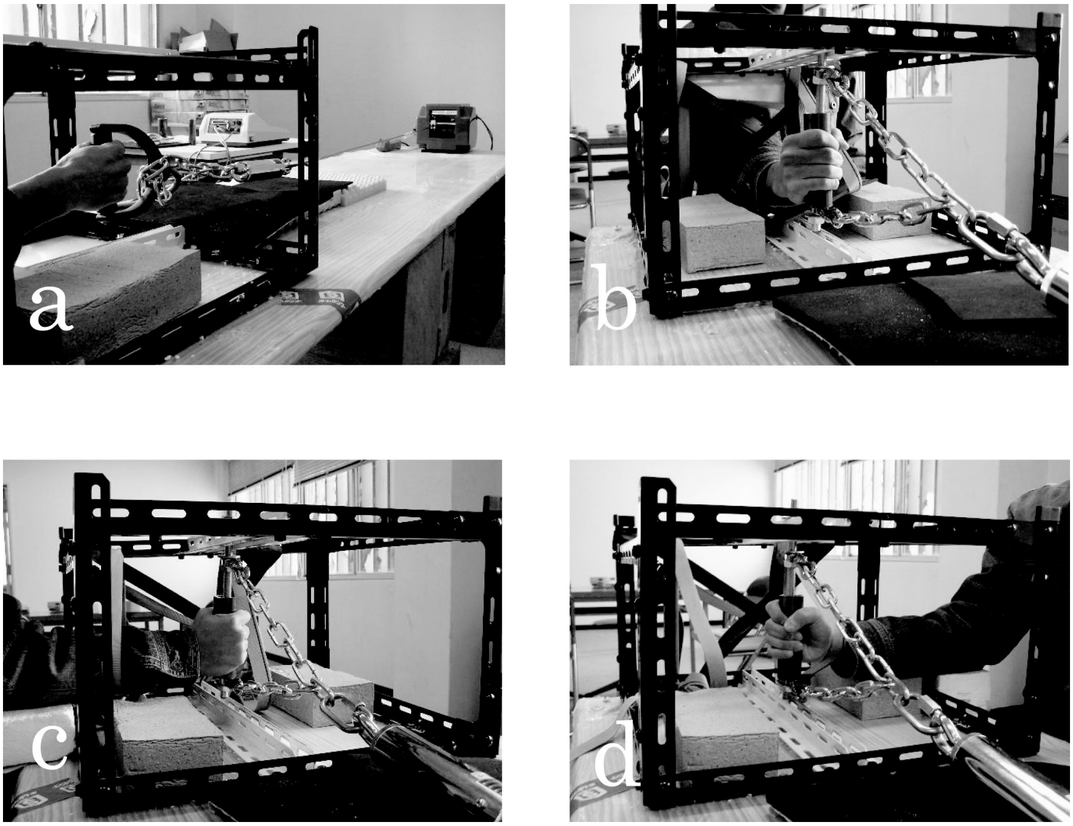

Fig. 2. Four directional conditions to measure grip and hold strengths using the experimental equipment (see text). a; the training strap was pulled in the forward direction, b; the handle part was pulled in the forward direction, c; the handle part was pulled in the back of the hand direction, d; the handle part was pulled in the palm of the hand direction.

forearm only could be measured. As the extension and flexion strengths of the *Artic. carpea* might be considerable contained, it should be noted that the strengths referred to in this study involves not only grip strength but also hold strength.

Statistical analysis: In this paper, the value obtained when the handle part was pulled in the forward direction was termed the "forward value". Similarly, the value obtained when the handle part was pulled in the direction of the back of the hand was termed the "back of the hand value", and that obtained from the direction of the palm was termed the "palmar value". For comparison, grip and hold strengths measured were standardized by the subject's grip strength measured by the hand dynamometer. The larger of two measurements was used for analysis. All statistical analyses were performed using SPSS. Bonferroni multiple comparisons were used to compare the four groups. Bonferroni multiple comparisons for paired samples were used to compare and evaluate the effects of the pulling direction. The statistical significance level was set at $p<0.05$.

RESULTS

Table 2 shows the mean forward values for each group when the strap and two different caliber steel pipes were used as the handle part. When using the strap, the mean forward values ranged from 127.7% to 138.0%. There was no significant difference between groups, though the elderly female group had slightly lower forward values. When using the small-caliber steel pipe, the mean forward values ranged from 130.3% to 139.4%, except for that of the elderly female group, which was 115.9%; these values when compared with the mean forward value of the elderly male group showed a significant difference ($p<0.05$). When using the large-caliber steel pipe, the mean forward values ranged from 104.1% to 121.3%, with no significant difference between pairs of groups. Both female groups had lower mean forward values than the males.

Table2. Mean and SD of experimental grip strength measured when a strap or handle of caliber steel pipes was pulled forward (%).

Group	Kind of handle		
	Strap	Small caliber steel pipe	Large caliber steel pipe
EM	138.0±31.53	139.4±26.25	121.3±24.79
EF	127.7±43.92	115.9±37.38	104.1±39.03
YM	130.0±16.42	131.9±16.57	114.7±16.40
YF	133.1±11.95	130.3±22.61	106.7±12.93
Multiple t-test		EM-EF*	

EM:Elder male, EF:Elder female, YM:Young male, YF:Young female

*:p<0.05

Table 3 shows the mean forward, back of the hand, and palmar values for each group when the small- and large-caliber steel pipes were used as the handle part. With the small-caliber pipe, the mean back of the hand values ranged from 59.9% to 90.8%. The elderly female group had a significantly lower mean back of the hand value. Comparing the elderly females and young females, the former had a significantly lower mean back of the hand value ($p<0.05$). The mean palmar values ranged from 63.2% to 75.4%, corresponding to about one-half of the forward values for each group, respectively. No significant differences were seen between pairs of groups.

With the large-caliber pipe, the mean back of the hand values ranged from 64.9% to 81.5% and the mean palmar values ranged from 50.7% to 67.0%. There were no significant differences between pairs of groups.

Table 3. Mean and SD of experimental grip strength measured when handles of caliber steel pipes were pulled in three directions (%).

Group	Pulling direction(Small caliber steel pipe)			Pulling direction(Large caliber steel pipe)		
	F	B	P	F	B	P
EM	139.4±26.25	77.9±27.30	75.4±24.98	121.3±24.79	77.0±21.41	66.4±15.95
EF	115.9±37.38	59.9±36.55	70.0±31.55	104.1±39.03	64.9±31.44	67.0±33.52
YM	131.9±16.57	80.4±14.37	63.2±15.66	114.7±16.40	73.3±15.65	50.7±14.00
YF	130.3±22.61	90.8±31.29	64.8±17.85	106.7±12.93	81.5±7.50	59.3±12.78
Multiple t-test	EM-EF*	EF-YF*				

EM:Elder male, EF:Elder female, YM:Young male, YF:Young female

F:Forward direction, B:Back of hand direction, P:Palmar direction

*:p<0.05

Table 4 shows the three mean values for all four groups as the steel pipes were pulled in three directions. Generally, in the young groups the mean back of the hand value was 75% of the forward value and the mean palmar value was about 50% of the forward value. In the elderly groups, the mean back of the hand and palmar values were both about 50% of the forward value. Considering the elderly groups, the mean forward values using both small- and large-caliber steel pipes were significantly higher than the back of the hand and palmar values ($p<0.05$), and there was a significant difference between the mean back of the hand and palmar values with the large-caliber pipe in the elderly male group ($p<0.05$) but not in the elderly female group. However, there was no significant difference between the mean back of the hand and palmer values in the elderly male and female groups. In the young groups, with both pipes, the mean forward value was higher than the back of the hand value, and the mean back of the hand value was higher than the palmar value. There were significant differences between all pairs of mean values in all groups ($p<0.05$).

Table 4. Mean and SD of experimental grip strength measured when handles of caliber steel pipes were pulled in three directions (%).

Group	Pulling direction (Small caliber steel pipe) F	B	P	Multiple t-test for paired sample		
EM	139.4±26.25	77.9±27.30	75.4±24.98	F-B*	F-P*	B-P
EF	115.9±37.38	59.9±36.55	70.0±31.55	F-B*	F-P*	B-P
YM	131.9±16.57	80.4±14.37	63.2±15.66	F-B*	F-P*	B-P*
YF	130.3±22.61	90.8±31.29	64.8±17.85	F-B*	F-P*	B-P*

Group	Pulling direction (Large caliber steel pipe) F	B	P	Multiple t-test for paired sample		
EM	121.3±24.79	77.0±21.41	66.4±15.95	F-B*	F-P*	B-P*
EF	104.1±39.03	64.9±31.44	67.0±33.52	F-B*	F-P*	B-P
YM	114.7±16.40	73.3±15.65	50.7±14.00	F-B*	F-P*	B-P*
YF	106.7±12.93	81.5±7.50	59.3±12.78	F-B*	F-P*	B-P*

EM:Elder male, EF:Elder female, YM:Young male, YF:Young female
F:Forward direction, B:Back of hand direction, P:Palmar direction
*:P<0.05

DISCUSSION

A bus might stop suddenly to avoid a serious accident, and as a result standing passengers may fall and be injured. Various safety devices are used to prevent injury to bus passengers in such circumstances; for example, the handrail on the ceiling and the prop of the bus, the so-called "stanchion". Two or three kinds of stanchion are attached in most buses. The stanchion in a bus is generally thicker than that in a tramcar. In the case of a major transportation company with both bus and tramcar systems, three kinds of stanchion are used in buses (25.5 mm, 31.8 mm, and 38.0 mm diameter) and two in tramcars (20.7 mm and 30.3 mm).

Standing bus passengers can fall easily if they are unable to grasp any safety equipment in the event of a sudden stop. Observing standing bus passengers, it can be seen that not only their standing position but also the direction they are facing relative to the direction of travel varies between individuals. As well, passengers have different luggage with them when traveling on a bus. Is there an effective way for bus passengers to grasp the stanchion or a handrail to maintain their stability?

To determine the most effective way to grasp the stanchion or a handrail when standing on a bus, we constructed the experimental equipment described above and subjects were asked to grasp the handle part against a pulling force. We then recorded and analyzed maximum grip and hold strengths. Some important results were found that needed to be discussed in detail.

First, net grip strength was naturally higher in young groups than in the elderly. The value in the elderly of both sexes was about 70% of that in the young. The difference was the greatest between young men (50.5±6.64 kg) and elderly women (24.0±4.78 kg), with the strength of the elderly women being about 50% of that of the young men. It is not surprising that grip strength decreases in the elderly, because skeletal muscles deteriorate with age. Indeed, there has been an interesting report relevant to our research.

The Research Institute of Human Engineering for Quality Life(2001) investigated the diameter of a steel pipe or cylinder that Japanese individuals in their 20s to 80s found the most easy and comfortable. They concluded that most individuals felt the greatest ease or comfort when gripping or holding a pipe of 30 mm to 40 mm in diameter. However, the optimal value varied with age. There was a tendency for the most comfortable diameter to decrease as age increased, and this was especially marked in women over 70 years of age. The reason for this result is unclear, though it is likely that the elderly may feel more comfortable gripping a thinner pipe because of reduced muscle strength in their upper limbs.

Independent of sex and age, and using the same handle part, the forward value was the highest of the three values. It is necessary to examine how gripping power is generated when the handle is pulled in a certain direction. When the handle is pulled forward, it is wrapped around and gripped strongly by the subject's fingers. According to an anatomical text (Kaneko, 1975), the main muscles working in this situation are the *m. flexor digitorum superficialis* and *profundus* and the *m. flexor pollicis longus*. When the handle is pulled in the palmar direction, pinching rather than gripping power is needed to hold the handle, and the main muscles involved are the *m. flexor digitorum superficialis*, the *m. flexor pollicis brevis*, and the *m. adductor pollicis*. When the handle is pulled in the back of the hand direction, the working muscles are the *m. flexor carpi radialis* and the *m. flexor carpi ulnaris*. As the *m. flexor digitorum superficialis* and *profundus* are overextended in this situation, they are not working effectively (Nakano *et al*., 1982). The three strategies of handle gripping differ from each other, and it is possible that these differences lead to higher forward values.

Considering the mean forward values of all the groups, independent of sex and age, the mean values with the training strap and the small-caliber steel pipe were almost the same, but the mean value with the large-caliber pipe was lower than that of the other two. To simplify the comparison between the strength exerted when subjects gripped the two types of steel pipe, we discuss the middle finger only. Figure 3 shows a subject gripping and holding the two pipes used in this study with the thumb and middle finger only.

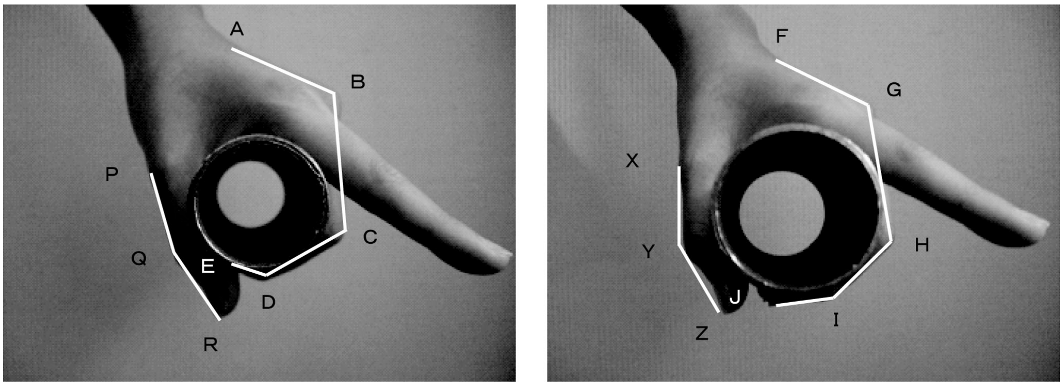

Fig. 3. Upper view of a left hand gripping the steel pipes used in the experiment. The first finger is not used to show the differences in the angles of each joint. Right: large steel pipe, 42 mm in diameter. Left: small steel pipe 33 mm in diameter. Here, points A and F are the projection point of the *Basis os metacarpale*, points B and G are the projection point at the metacarpophalangeal joint, points C and H are the projection point at the proximal interphalangeal joint, points D and I are the projection point at the digital interphalangeal joint, points E and J are the upper part of the middle fingernail, points P and X are the projection point at the metacarpophalangeal joint, points Q and Y are the projection point at the interphalangeal joint, and points R and Z are the upper part of the thumbnail.

Here, points A and F are the projection point of the Basis os metacarpale, points B and G are the projection point at the metacarpophalangeal joint, points C and H are the projection point at the proximal interphalangeal joint, points D and I are the projection point at the digital interphalangeal joint, points E and J are the upper part of the middle fingernail, points P and X are the projection point at the metacarpophalangeal joint, points Q and Y are the projection point at the interphalangeal joint, and points R and Z are the upper part of the thumbnail. ∠ABC, ∠BCD, ∠CDE, and ∠PQR are 120°, 115°, 132°, and 162°, respectively. ∠FGH, ∠GHI, ∠HIJ, and ∠XYZ are 125°, 125°, 143°, and 150°, respectively. When the subject grips and holds the small-caliber steel pipe, all the angles except ∠PQR are smaller than that with the large pipe. As the insertions of the *flexor digitorum superficialis* and *profundus*, which flex the middle finger are steady, the lever arm in each finger joint is longer for the small pipe than for the large pipe. Therefore, the subject can generate a larger torque when he grips the small-caliber pipe. These factors might also explain why the mean forward value with the large-caliber steel pipe was lower than the other two, the small-caliber steel pipe and the training strap.

The mean back of the hand values in the elderly groups were about 50% of the forward values, but those of the younger groups were about 75%. What caused this difference? After measurement of back of the hand values, the comments of the elderly subjects included: "I let go the handle part before my best effort because I was scared about my wrist", "Because I had learned in a health seminar that the bone mass density lowers with ageing, I did not overwork". These comments suggested that many elderly subjects followed the instructions given before the experiment. It was therefore natural that they would not have made their best effort when the back of the hand values was measured.

When a bus unavoidably stops suddenly, standing passengers are thrown from their position. To prevent themselves from falling, passengers should grip fixtures in the bus. Which hand they use to grip and where they stand are very important. The results of this experiment provided important information for standing bus passengers, especially for the elderly. One is that a thin stanchion or handrail is better than a thick one, as shown by the finding that the mean values with the training strap and the small-caliber steel pipe were almost the same, but the mean value with the large-caliber pipe was lower. Another is that standing passengers should switch the hand that grips a stanchion or handrail based on which side of the bus they are on; that is, if the passenger is standing on the right side of the bus and facing the windows, they should grip fixtures such as a stanchion with their right hand, and vice versa. In this position, the standing passenger would be thrown in the direction of travel if the bus stopped suddenly. However, as this situation corresponds with the pulling of the experimental handle part in the forward direction, the passenger would generate the largest grip and hold strengths in this way, and the probability of their maintaining their balance would be the greatest.

It is necessary to note that in this study all the values discussed were standardized by grip strength. Because grip strength declines with age, we should not be overconfident even if our relative values are high. It must also be noted that differences in the passenger's posture, height, and weight would cause different results when a bus stop suddenly, even if the measured grip and hold strengths were the same. These issues remain as matters to be investigated further.

This study was part of the research program of the Human Ergology Society, with financial support from the Ministry of Land, Infrastructure and Transport.

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