

Comparison between static maximal force and handbrake pulling force

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Abstract: The measurement of maximum pulling force is important not only for specifying force limit of industrial workers but also for designing controls requiring high force. This paper presents a comparison between maximal static handbrake pulling force (F_{ST}) and force exerted during normal handbrake pulling task (F_{DY}). These forces were measured for different handle locations and subject characteristics. Participants were asked to pull a handbrake on an adjustable car mock-up as they would do when parking their own car, then to exert a force as high as possible on the pulled handbrake. Hand pulling forces were measured using a six-axes force sensor. 5 fixed handbrake positions were tested as well as a neutral handbrake position defined by the subject. F_{ST} and F_{DY} were significantly correlated. Both were found to be dependent on handbrake position, age and gender. As expected, women and older subjects exerted lower forces. F_{ST} was significantly higher than F_{DY} . The ratio FmR (F_{DY} divided by F_{ST}) was also analyzed. Women showed higher FmR than men meaning that the task required a higher amount of muscle capability for women. FmR was also influenced by handbrake location. These data will be useful for handbrake design.

Keywords: force capacities, ergonomics, handbrake, hand pulling strength, automotive

1. Introduction

The measurement of maximum pulling force is important not only for specifying force limit of industrial workers but also for designing controls requiring high force. When designing a control like handbrake, engineers have to take into account the functional capacities of the target population of users. Users, such as elderly, women, children, or handicapped people, should be able to operate, use or manipulate a control that is designed for them. It is well known that physical strength varies widely among individuals. A product should be designed such that the weaker people are able to use it safely and comfortably whereas the stronger users can interact with the product without damaging it [3].

Many studies have shown that the maximal force-producing capability varies considerably between people and between tasks [1]. As a consequence, predicting the force exertion capacities of a target population for a given task requires extensive force

measurements. This is why Daams [3] proposed to build up an “Atlas of Human Force Exertion” in order to guide designers.

On the other hand, Digital Human Models are more and more used to assess the ergonomics of a product during the early stage of the product design. However, the DHM ability to assess dynamic motions is still a requirement of car manufacturers [8]. It is important to implement force exertion capacities into the DHM tools to provide the designer with efficient models. Due to the large variability in the human capacities and behaviors and the complexity of the musculo skeletal system, we have proposed a pragmatic data-based approach which allows the prediction of variation range of hand and foot maximum force on a control for DHM applications [9].

This study was carried out within the framework of the European project DHErgo. This project aimed to develop digital human models and to collect human functional data for a better evaluation of a product at its early stage of design. This project was fo-

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cused on the ergonomics of automotive. This paper presents the results gathered during the case study dealing with the handbrake pulling task.

The handbrake pulling task is a good example to show how important it is that the designers take into account the force exertion capacities of the future users. It is obvious that a short elderly woman who lent her car to her grandson **must** be able to release the handbrake after him.

The objective of this paper is to present the results of the experiment carried out to investigate the relationship between static maximal force and force exerted during the actual task for different handbrake locations and participant characteristics.

2. Materials and methods

2.1. Participants

20 subjects participated in the experiments. They were divided in 4 groups according to their age and gender (Table 1). Only people with a height within an interval of + or -50mm around the 50th percentile of their age and gender group were selected. They were recruited according to the following criteria:

- Currently driving
- No sport competition
- No history of trauma
- No particular known orthopedic or neurological disorders
- No medical treatment
- No recent serious disease
- No difficulties in normal daily activities
- For older participants: to be able to get up from a chaise and climb 10 steps without difficulty

Table 1
Participant groups and characteristics (mean values)

	YM	YF	OM	OF
N	5	5	5	5
Age	24	29	74	69
Gender	male	female	male	female
Height	1778	1636	1705	1594
Weight	72	55	76	63
BMI	23	20	26	25

Y: young, O: older; M: male; F: female; BMI: body mass index

2.2. Experimental set-up

An adjustable car mock-up representing the driving environment was used (Figure 1). Only the

handbrake initial position was adjusted for each configuration. The other parameters were fixed (Table 2).

A VICON optoelectronic system with 10 MX40 cameras was used to capture the motions. This system was synchronized with four 6-axis force sensors placed in the mock-up to record the forces applied by the participants on the handbrake, steering wheel, mock-up floor and seat.

Table 2
Fixed handbrake characteristics

Parameter	Value
Initial angle of handbrake with horizontal	10°
Final angle of handbrake with horizontal	40°
Length of handbrake (R)	300 mm
Travel length	157 mm
Handbrake stiffness	11.7N/°

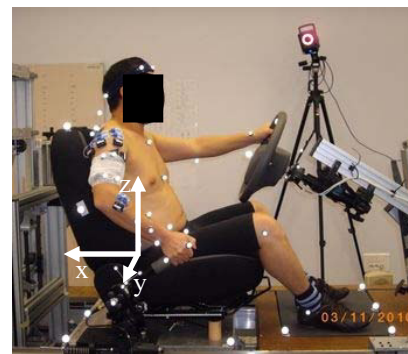


Figure 1. Positions of the tip of the handbrake handle for the 5 fixed configuration in the SAE reference system

2.3. Test conditions and experimental procedure

2.3.1. Training session

At first, participants tested 3 calibration configurations in order to familiarize themselves the discomfort assessment questionnaire and test procedure. Two configurations were supposed to be uncomfortable and an “average” one was considered to be less uncomfortable.

2.3.2. Handbrake test session

Five test configurations were defined in a common vehicle coordinate system centered at a seat reference point (Figure 2). They were selected to cover a large range of possible handbrake positions at the end of travel, based on the data provided by the three car manufacturers participating in the DHErgo Project. These configurations were all located in the same Y

plane along the seat. They were tested in a random order after the training session.

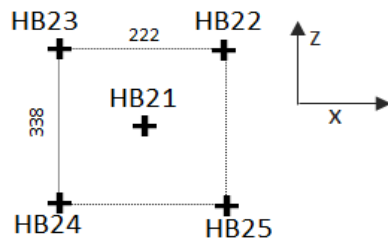


Figure 2. Positions of the tip of the handbrake handle for the 5 fixed configurations in a vehicle coordinate system centered at a seat reference point [7]

For each tested configurations, the subject was allowed to adjust the steering wheel in the vertical and longitudinal direction but not the seat. All subjects were recruited to be close to the 50th percentile of their gender, thus two gender specific positions were defined according to the mean values of the seat H-point for each gender. For male subjects, the seat was positioned so that the H-point coincides with the reference H-point and for female subjects, the seat was positioned 53 mm frontward.

Before recording the handbrake pulling movement, the subject was asked to fill up a questionnaire reporting the perceived discomfort. A modified CP-50 discomfort scaled was used. Discomfort ratings were composed by 5 categories from very weak to very strong and ratings from 1 to 10 within the categories [2]. Participants were asked to focus on the ascending part of the handbrake operation. The handbrake was repositioned in its initial position by the experimenter. The subject could manipulate the handbrake as often as needed when answering the questionnaire.

Subjects were instructed to pull the handbrake naturally as they would do when parking a car on a flat ground. For the pulling movements, the subjects started from the initial posture with the right hand on the handbrake and the left one on the steering wheel. The subjects were asked to pull the handbrake, rest for 3 seconds and place the hands on the steering wheel to keep a standard driving posture with a 10:10 hand position. After a handbrake pulling motion, the subjects were asked to pull the handbrake as much as possible from its pulled position when a red light turned on, then to maintain the force level until the light turned off. The light duration was fixed at 5 seconds, also controlling the data registration. For

each handbrake test configuration, both the natural pulling and maximum voluntary static pulling tests were repeated twice.

The tested configurations were distributed in 5 fixed handbrake configurations and 3 neutral configurations. For a neutral position, the subjects were asked to take time to choose their preferred handle position with help of the experimenter. The first neutral configuration was done before the first tested configuration. The second neutral configuration was done between the second and third tested configurations. The last neutral configuration is done after the last tested configurations. The trial order of the five fixed handbrake configurations was randomly chosen. In order to investigate hand force perception, the static hand forces corresponding to six force levels (rest, very low, low, medium, high, maximum) were also recorded for the medium handle position (HB21). Two repetitions were imposed for each force level except for the rest.

In total, 46 trials were measured for each subject: 3 for calibration, 11 for force perception, 32 for natural handbrake pulling and static maximum force exertion.

In this paper, only dynamic pulling force and static voluntary maximum forces were presented.

2.4. Data processing

2.4.1. Maximal static force F_{ST}

Maximal static force trials were recorded after each handbrake pulling task for each test configuration. During the pulling task, participants were instructed to pull the handbrake “normally” as they would do when parking a car. As a consequence, the brake was not always pulled at its end stop. Figure 3 shows an example of the resultant force during the force exertion. The maximal static force F_{ST} was defined as the mean force calculated on an interval of 3s starting after the first pick of force [1]. The beginning of the interval was selected manually by inspection of the force variations (Figure 3).

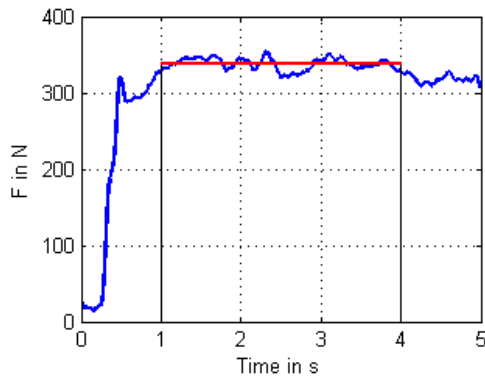


Figure 3. Illustration of the force pattern recorded during the trials and F_{ST} definition

2.4.2. Maximum dynamic force F_{DY}

The maximal dynamic pulling force F_{DY} was identified from the force recorded during the handbrake pulling task (Figure 4).

2.4.3. Other parameters

In addition to F_{ST} and F_{DY} , following parameters were defined:

- **RUF**: tangential component of the force (F_{ST} or F_{DY}) with respect to the handbrake motion direction divided its norm. It represents the **Ratio** of "Useful" Force as the tangential component is the one that generates the motion of the handbrake.
- **FmR**: F_{DY} divided by F_{ST} for each configuration and subject.

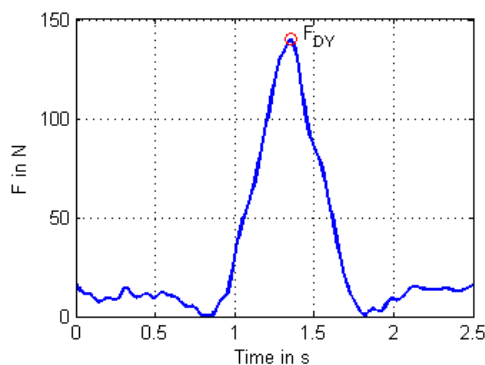


Figure 4. Illustration of the forces patterns recorded during the trials and maximum dynamic pulling force definition

2.4.4. Statistical analysis

The effects of Age (A) and Gender (G) were investigated with 2 simple analyses of variance.

In order to investigate the influences of the Group (age*gender) (Grp) and handbrake Configuration (C), a Generalised Linear Model (1) was used.

$$\text{Variable} = k_1 + k_2 \text{ Grp} + k_3 \text{ C} + k_4 \text{ Grp} * \text{C} \quad (1)$$

3. Results

3.1. Maximal static forces

F_{ST} was significantly influenced by age and gender. Women exerted lower forces than men and older than young participants (see Table 3). Young men had the highest F_{ST} .

As shown in Table 3, F_{ST} was also significantly influenced by the position of the hand brake ($p=0$). There was no significant difference between F_{ST} recorded for the configurations HB21, HB23, HB24 and the neutral position. However, in average, F_{ST} was the lowest for the position HB22 (high and backward) and the highest for the position HB25 (low and backward).

The direction of F_{ST} (RUF_{ST}) was not influenced by age. But men had significantly higher RUF_{ST} than women. It means that the amount of force exerted in the direction of the handbrake motion was higher for men.

The handle location had a significant effect on RUF_{ST} . This ratio was especially low for the configuration HB23 (low and forward, Figure 2).

3.2. Dynamic pulling forces

As presented in Table 3, F_{DY} depended on subject group and handbrake location. There was no interaction between these two factors.

Young males exerted significantly higher forces than the other groups for all the tested configurations.

Like F_{ST} , F_{DY} was significantly lower for the configuration HB22 (high and backward) and significantly higher for the configuration HB25 (low and backward).

RUF_{DY} was also influenced by subject group and handbrake location. Young men had significantly higher RUF_{DY} than the other groups. The ratio of force exerted in the direction of the handbrake motion was especially low for the configuration HB23 (high and forward) (Table 3).

3.3. Comparison between F_{ST} and F_{DY}

For each tested configuration, as the maximal static force was measured (F_{ST}), then it was possible to compare it with the force exerted during a dynamic pulling movements. A paired t-test showed that F_{ST} was significantly higher than F_{DY} ($p=0$). However, for 20.7% of the trials, F_{DY} was higher than F_{ST} . Moreover, F_{ST} and F_{DY} were significantly correlated ($r=0.692$, $p=0$).

F_{DY} varied between 32% and 147% of F_{ST} with an average percentage of 79.5%. The ratio FmR ($F_{DY}/$

F_{ST}) varied according to the configuration and group. FmR was significantly higher for the configuration HB22 (high and backward) than for HB21, HB23 and HB24 (Figure 2 and Table 3). FmR was significantly lower for the configuration HB25 (low and backward).

A significant gender effect was also observed for FmR. The handbrake pulling task required a lower amount of their force-producing capability for the men compared to women.

Table 3
Mean values and standard deviations of the static and dynamic maximum forces and their ratios

	FST _{ST} (in N)		RUF _{ST}		F _{DY} (in N)		RUF _{DY}		FmR						
	mean	std	mean	std	mean	std	mean	std	mean	std					
O	196	55	A***	0.94	0.05	A ns	159	39	A***	0.93	0.06	A*	0.85	0.2	A***
Y	293	128		0.95	0.05		198	70		0.95	0.05		0.74	0.25	
M	187	46	G***	0.96	0.04	G***	167	44	G***	0.93	0.05	G*	0.92	0.22	G***
F	300	124		0.93	0.05		191	70		0.95	0.06		0.67	0.17	
OF	186	54	Grp***	0.93	0.05	Grp***	170	41	Grp***	0.93	0.05	Grp***	0.95	0.2	Grp***
OM	206	55		0.95	0.05		148	34		0.93	0.07		0.75	0.16	
YF	188	35		0.93	0.05		164	48		0.93	0.06		0.89	0.25	
YM	395	98		0.96	0.03		233	72		0.96	0.04		0.6	0.15	
HB21	237	104	C***	0.97	0.02	C***	174	59	C***	0.96	0.03	C***	0.8	0.22	C***
HB22	202	106		0.95	0.04		151	51		0.93	0.04		0.92	0.21	
HB23	199	70		0.88	0.06		176	58		0.83	0.07		0.82	0.21	
HB24	239	94		0.91	0.05		190	67		0.95	0.03		0.82	0.24	
HB25	280	106		0.94	0.04		203	62		0.97	0.02		0.69	0.22	
All	244	109		0.94	0.05		179	60		0.94	0.06	GrpxC***	0.79	0.24	

A: age; G: gender; Grp: group; C: configuration; std: standard deviation. ***: $p<0.001$; **: $p<0.01$; *: $p<0.05$; ns: $p>0.05$.

4. Discussion

Maximal static forces were measured on each handbrake position. The analyses showed that these force-producing capabilities depended on the position of the handbrake and also on age and gender. The strength is known to decrease with age and women have lower force capabilities than men (See for example [1] [3] [4] [4] or [5]). As expected, our results showed that young men exerted significantly higher forces than young women and older participants. No significant difference was found between the forces exerted by older men and women. However, only 20 subjects participated in the experiment and this is not

enough to obtain results representative of the population.

The force-producing capabilities were found to be the highest for the low and backward handbrake and the lowest for the high and backward configuration.

The direction of the forces in the handbrake coordinate system was also analyzed for both dynamic and static pulling situations (RUF_{DY} and RUF_{ST}). Nearly 94% of the force was exerted in the Handbrake motion direction. It depended on handle position and subject group. The force direction deviation from its nominal direction is generally supposed to reduce joint loads thus increasing force exertion capacity. Therefore, it will be interesting to investigate the relationship between posture and maximal force exertion capacities in future work.

The maximal forces applied to the handbrake during the pulling task (F_{DY}) were compared with the maximal static forces (F_{ST}). The normal use of a handbrake is a dynamic task. The forces applied at the end of a pulling movement may be higher than the maximal static forces. However, it is difficult to hold a high force level for a period of time like the maximal static forces. This may partly explain why for 20.7% of the trials had F_{DY} higher than F_{ST} . People do not need to exert their maximum force when pulling a handbrake naturally. This is the case for the younger men who only used 60% of their capacity. It is interesting to see that the maximum dynamic force when tightening the handbrake was 233 N in average for the young males, higher than the maximal static hand force of the three other groups. This means that it is likely that the females and older people may not be able to release a handbrake tightened by a young male.

It should be pointed out that only 20 subjects participated in the experiment. Due to large variability in functional capacity between people, the data collected in the current work is far from representative of the population of drivers. Moreover, only 5 fixed handbrake positions were tested in one lateral plane and the handbrake stiffness and geometry were the same for every configuration. In future work, further measurements should be done.

In order to pursue this study, the effects of subject characteristics and handbrake configuration on postures (joint angles) and joint torques will be investigated. The relationships between postures and force capabilities will be analyzed. The final goal is to be able to build discomfort indicators and to implement these data into a DHM. Moreover, this data will be useful for handbrake design.

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