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The Effects of Grasp Conditions on Maximal Acceptable Combined Forces (pushing and pinch forces) for Manual Insertion of Snap Fasteners

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Abstract

The objective of this study was to determine the effects of grasp conditions (types of grasp, grasp width, glove and types of coupling) on maximal pushing force (MPF) and required pinch force (RPF) during snap fit assembly. The results indicated that the type of grasp, the type of coupling and wearing gloves have significant ($p<0.05$) effects on both MPF and RPF. Regarding the pair wise comparison, there was no significant difference in the effect between the lateral pinch and chuck pinch. MPF and RPF were also not affected significantly by the width of the grasp. Furthermore, there was an interactional effect between the type of coupling and the wearing or rather not wearing a glove. This, of course, only affected the MPF.
Keywords: Snap fit; Pinch-Push force; Grasp conditions.

1. Introduction

Snap fit assembly has become more important in automotive manufacturing and within its subcontractors as well as in the consumer goods industry. It is assumed that more than 20% of all fasteners in a vehicle are snap fit components (Hübner qtd.in Landau et al.(2009). The reason for this development is particularly related to the increased economic benefits that occur through the accelerated assembly task. However, the ergonomic aspects of snap fit assembly have not been studied sufficiently. The geometrical form of many snap fasteners constrains the operators to use a precise pinch grasp during insertion (see Fig.1). Sometimes it requires high force levels and repetitive exertion (more than one thousand times within a shift). Therefore, it can lead to musculoskeletal disorders such as arthrosis and repetitive strain injuries such as tendosynovitis. The stresses generated under these situations were reviewed by Hagberg et al. (1995). Knowledge of the physical strength of users related to grasp conditions can be utilized in designing snap fasteners to avoid musculoskeletal disorders. Furthermore, the consideration of ergonomic aspects in early phase of product-development-processes can contribute to an increase of productivity. In order to investigate these effects, first the relevant grasp conditions for snap fit assembly have to be specified. The observation of snap fit variations refers predominantly to geometrical and material parameters which influence the grasp stability.

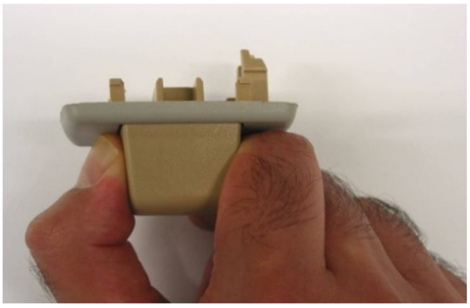

Fig. 1. Use of pinch grasp during insertion of snap fasteners

We classify the geometrical parameters into dimension and form related attributes. The material parameters can be divided into “young’s modulus” (elasticity/flexibility) and “friction coefficient” (slipperiness). Furthermore, the grasp stability can be influenced by the type of pinch grasp and the type of coupling during insertion. The relevant types of pinch grasp for snap fit assembly can be divided into pulp pinch, lateral pinch and chuck pinch. The definition of these terms according to Kumar (1999) is as follows:

In the pulp pinch, the pad of the distal phalange of the thumb opposes the pad of the distal phalange of the index finger of the same hand. In the lateral pinch, the thumb

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opposes the radial lateral aspect of the index finger in the clenched fist. The chuck pinch is similar to the pulp pinch except that the thumb opposes both the index and middle fingers simultaneously. Figure 2 shows these different types of pinch grasps "pulp pinch, lateral pinch and chuck pinch" from left to right.

Fig. 2. Different types of pinch grasps

There are many studies in literature regarding this topic. Some investigations only consider certain effects arising from pinch forces. They are classified into human related effects (proband collective and posture) and object related effects (shape, size and material of contact surface). Regarding to proband collective, Imrahn et al. (1989) explored the empirical relationships among different types of pinches in three age groups. In addition, Mathiowetz et al. (1985) have studied the influence of gender and the right-/left hand on the hand strength for the tip pinch, key (lateral) pinch and palmar (pulp) pinch. Schaub et al (2010) have analyzed the lateral pinch and chuck pinch strengths of workers (males) in the automotive industry. The posture of hand-arm-system can influence also the pinch force. This assertion was tested by several scientists. The influence of wrist position on different types of pinch strength was investigated by Imrhan (1991). The Study of Snook (1999) has presented the maximum acceptable forces for repetitive wrist extension with a pinch grip. The influence of arm position on the pinch grip strength of female dentists in standing and sitting positions was studied by Catovic e.c. et al (1991). The third main group of investigations refers to object related effects. Imrahn et al.(1995) and Domalain et al. (2008) studied the effects of pinch width on pinch forces. The effect of grip span on isometric grip force and fatigue of the flexor digitorum superficialis (FDS) was investigated by Blackwell JR. et al. (1999). Their results showed that the fatigue of FDS did not change as a function of grip size. However, middle grip sizes allowed for greater absolute forces than the small or large size. The effect of handle shape on hand muscle load and pinch force was studied by Dong H. et al. (2007). In this study, eight custom-designed dental scaling instruments with different handle shapes were used to perform a simulated tooth scaling task. The results demonstrated that the instrument handle with a tapered, round shape and a 10 mm diameter required the least muscle load and pinch force when performing simulated periodontal work. Hallbeck, M.S. and McMullin, D.L. (1992) have published the results of their pilot study for the effect of gloves, wrist position and age together on peak three-jaw chuck pinch force.

Some other studies focus on the push/pull forces during the pinch grip. For example, Potvin et.al (2006) studied the maximal acceptable push forces for the lateral pinch and pulp pinch. Their study includes only female participants and also considers the effect of insertion frequency and wrist posture. In an elaborate study, Peebles et al. (2003) have investigated the maximal pulling forces during pulp pinch and chuck pinch for 10 age groups among 2 and 90 years old men and women. They have studied three variants of width of grasp for these two pulling pinch forces. Push forces have also been studied by Snook et al. (1991). They have published the maximum acceptable forces of pushing for males and females. These data have been compiled into gender related tables in consideration of anthropometric characteristics, task frequency, distance, height and duration. Greig & Wells (2004) have measured the prehensile grasp capabilities with a device. They have measured the isolated maximal forces and moments along and about the three orthogonal axes and a maximal grip force. Bucholz et al. (1988) have investigated the relationship between grip force and pull force in a pulp pinch. The relationship between safety margin and force level during an isometric push task in a lateral pinch posture was studied by Na Jin Seo (2009). He measured the voluntary grip force and minimum required grip force during exertion of 20%, 40%, 60%, 80% and 100% of maximum push force. Then he estimated the mean safety margin by the difference between voluntary and minimum required grip forces. The present study tries to extend these pieces of knowledge by consideration of other relevant aspects for snap fit assembly such as the geometry of objects, material of surface contact between subjects and objects as well as different types of grasp.

2. Method

The main influencing factors to measure the maximum action forces were classified into four categories according to Wakula et al. (2009): 1) Factors, which are related to the method of experiment 2) inter-individual factors 3) intra-individual factors 4) environmental influences. The factors of group1 are configurable and contain body posture, body supports, force directions and position of force application point. In sections 2.2 to 2.4, we describe how the present study considered these factors. The biomechanical and physiological factors such as weight, gender and anthropometrical data of subjects (inter-individual factors) are described in detail in the subsection subjects. Groups 3 and 4 involve psychological factors such as skill and motivation. They were not subsumed and were accepted as variables.

2.1 Subjects

26 male students from the age of 20 to 30 participated in the study. All participants were in good constitution and had no history of upper limb pain or musculoskeletal disorders. Their mean age, stature and weight was 25.2 years (SD 3.7), 179.5 cm (SD 4.9) and 80.2 kg (SD 12.9), respectively. Other anthropometric measures were obtained from each participant with regard to the hand finger system, which may influence the maximal pinch and pushing forces. Table 1 shows these anthropometric data for participants of the present study. In order to obtain the finger span, subjects were instructed to extend their index finger and to abduct their thumb. For this posture of the hand, the distance between the tip of the index finger and the tip of the thumb was measured.

Table 1
Anthropometric data of participants' fingers

	Thumb Length (mm)	Thumb Breadth (mm)	Index Length (mm)	Index Breadth (mm)	Finger span(mm)
Mean	6.91	2.36	8.16	1.86	15
Standard deviation	0.66	0.17	0.69	0.16	0.89

2.2 Body posture

In order to obtain reproducible results, all participants were instructed to maintain a standard position for the force measurements. In all the experiments, the subjects stood at a 90° angle adjacent to a desk (Fig. 3). The height of the desk was adjusted to the stature of the subjects so that their thumbs had a vertical distance of 1cm to the measuring plate on the desk with an extended hanging arm. The forearm and wrist for the lateral pinch-push force exertions were in a position in such a way that the palm was facing backwards (upper arm turned 90°) and the wrist was in line with the straight forearm (Fig. 4). The forearm and upper arm for pulp/chuck-pinch pushing force exertions were in a neutral zero position and the wrist was 90° flexed (Fig. 5). In all experiments, the subjects were allowed to lean sideward in order to use their body weight during the force exertion. The subjects were instructed to use only the defined surface of dynamometer during the force exertions. They were not allowed to firm up their fingers on other surfaces or edges of the dynamometer.

Fig. 3. Body Posture during force exertion

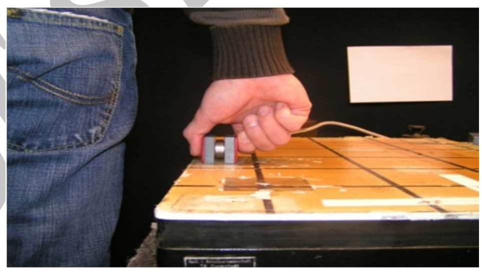

Fig. 4. Hand-Arm Posture for lateral pinch force exertion

Fig. 5.Hand Posture for pulp/chuck pinch force exertion

2.3 Experimental setup

With a non-slip measuring plate (Krag SWISS 9162A) on a height adjustable desk, the push (insert) forces were obtained. Pinch (grip) forces were obtained by using a dynamometer (Kistler type 9117A1.5).The subjects pushed the dynamometer against the measuring plate in the described posture (Fig. 6). The force, which was applied at the designated area of both piezoelectric force transducers, caused a voltage change. Due to the linear relationship between the produced voltages and the applied force, both devices were calibrated. Therefore, the calibration only required the voltage reading at zero and at a predetermined fixed weight (10 kg) to calculate the slope of the line. Prior to the recording of each data set, the electrostatic charging was zeroed by means of a reset key.

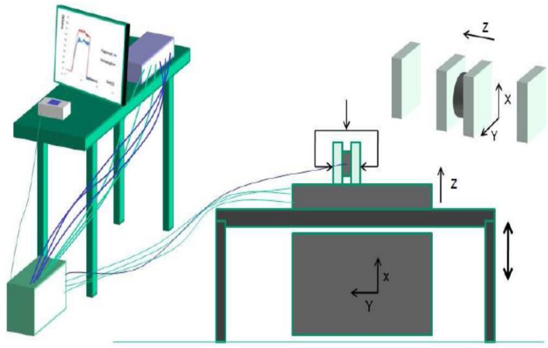

Fig. 6. Experimental setups for recording of push and pinch force

2.4 Experimental design

In order to analyze the effect of grasp conditions on maximal acceptable pinch-push forces, we varied the corresponding parameters within three series of experiments. Therefore, each experiment was conducted separately. All experiments were executed in groups of 3-4 people. (The subjects of each group executed the experiments one after the other). In a pretest, this group size was found to be preferable, because the recovery time for each subject could be used effectively. The subjects had to recover after force exertion for each experimental variant. The recovery time was determined using Rohmert's equation (1960a.) as a rule of thumb. However, the equation (1) is developed for arm and body forces.

$$Z_{er} = 18.\left[\frac{t}{T}\right]^{1.4}.\left[\frac{t}{T} - 0.15\right]^{0.5}.100\% \quad \text{for } \frac{k}{K} > 0.15 \qquad (1)$$

Z_{er}: Recovery time in % of t   t: Holding time in Min   T: Maximal holding time in Min

k: Holding force in kg
K: maximal holding force in kg

The calculated recovery time (6.9 sec) was clearly under the time which actually occurred in our study. Additional recovery time in the present study was mainly caused by the rotation of the subjects within one group and the time taken to assume the instructed position. In order to obtain a standard recovery time for all subjects, a time of 2 minutes, according to Kroemer (1977), was used. To prevent any influences concerning learning effects, all experiments were executed in a totally randomized order. The subjects were asked to expend the maximal acceptable effort to push the dynamometer against the measuring plate. When required, the pinch force had to be increased in order to avoid the fingers from slipping off the dynamometer. The participants were instructed to exert their own acceptable self-regulated forces without the assistance of any external stimuli. After three seconds of force exertion, the experiment was stopped. For reliability of statistical data, each variant of the experiment was repeated three times.

Experiment 1:

In the first experiment, subjects should push the dynamometer against the measuring plate with three different types of grasps (pulp pinch, lateral pinch and chuck pinch). The width of the grip was constant and about 35mm. The subjects executed each variant of this experiment once wearing a cotton glove and once wearing no glove. Subjects performed maximum force exertions in six variants with three trials per variant for a total of 18 trials.

Experiment 2:

In this experiment two types of grasps (pulp pinch and lateral pinch) were examined with two different widths of grasps (35mm and 50 mm) (Fig. 7). The two widths were achieved by screwing a plastic adapter plate (same surface roughness) on both sides of the dynamometer. The modification of the adapter plates occurred only once for each group of participants. All experiments of this series were executed without a glove. Subjects performed maximum force exertions in four variants with three trials per variant for a total of 12 trials.

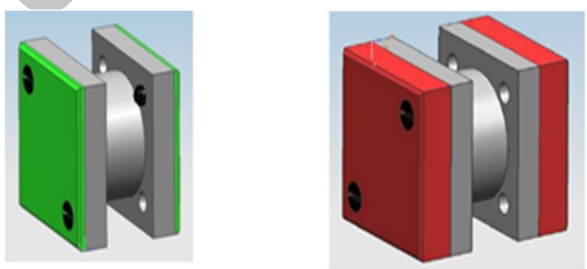

Fig. 7. Different widths of grasps used in experiment 2

Experiment 3:

In the third series of experiments, the effect of the type of coupling, according to picture 5(friction fit and form fit) (Fig. 8), was analyzed. The changing of the coupling was also achieved by screwing on a plastic adapter with a cavity only on one side of the dynamometer. These experiments were executed only in the lateral pinch posture. Subjects exerted the forces once wearing a cotton glove and once wearing no glove. They could firm up their fingers in the cavity of the form fit coupling (Diameter- 20mm). They performed maximum force exertions in four variants with three trials per variant for a total of 12 trials.

Fig. 8. Adapting of Coupling for friction fit and form fit

3. Results

In order to assure of data arithmetic mean of three repeated trials for each variant of experiment was determined at first. The maximal pushing force and its corresponding required pinch force for each variant and each subject were calculated automatically by the mean of an algorithm. The samples were compared using the analysis of variance (ANOVA) with repeated measures also called General Linear Model (GLM) with repeated measures.

3.1 The effect of the friction coefficient and type of grasp

The arithmetic means and standard deviations of MPF and RPF for three types of grasps (pulp-pinch, lateral pinch and chuck pinch) with and without a glove, respectively, are shown in Table 2. The results of the analysis of variance (ANOVA) for experiment 1 are presented in Table 3. The type of grasp as well a wearing a glove have a significant ($p<0.05$) effect on both MPF and RPF. With regard to paired comparisons, there was no significant difference in the effect between lateral pinch and chuck pinch. All other paired comparisons were significantly different. For all types of grasps, MPF reduced while RPF increased whenever the subjects wore a glove. Therefore, the sum of MPF and RPF for each type of grasp between wearing and not wearing a glove, was not significantly different. The Figs.9 and 10 present these changes for MPF and RPF respectively.

Table 2
The arithmetic means and standard deviations of MPF and RPF for three types of grasps

Type of grasp	MPF ± standard deviation [Newton]		RPF ± standard deviation [Newton]	
Pulp pinch	50.1	± 11.1	65.2	± 9.8
Pulp pinch (with glove)	39.0	± 8.9	70.0	± 13.0
Chuck pinch	64.5	± 13.0	97.3	± 18.2
Chuck pinch (with glove)	56.0	± 12.1	107.3	± 17.9
Lateral pinch	71.6	± 12.8	96.4	± 13.1
Lateral pinch (with glove)	58.0	± 14.2	108.0	± 18.8

Table 3
Analysis of variance (ANOVA) with repeated measures for MPR and RPF (N=26)

Aim Source	df	MSE	F	P-Value
Repeated measures for MPF				
Within subjects:				
Type of grasp	1.654	11675.173	95.455	0.00*
Glove	1.000	4802.514	38.783	0.00*
Repeated measures for RPF				
Within subjects:				
Type of grasp	1.907	21806.797	140.199	0.00*
Glove	1.000	3018.090	30.260	0.00*

0,05 significance level(*).

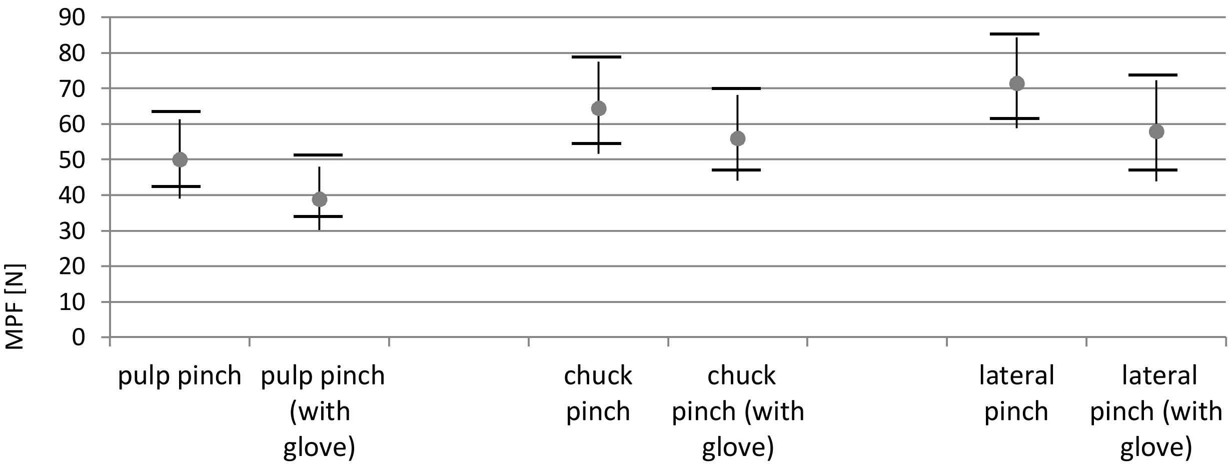

Fig. 9. Changes of MPF for all type of grasps in this study

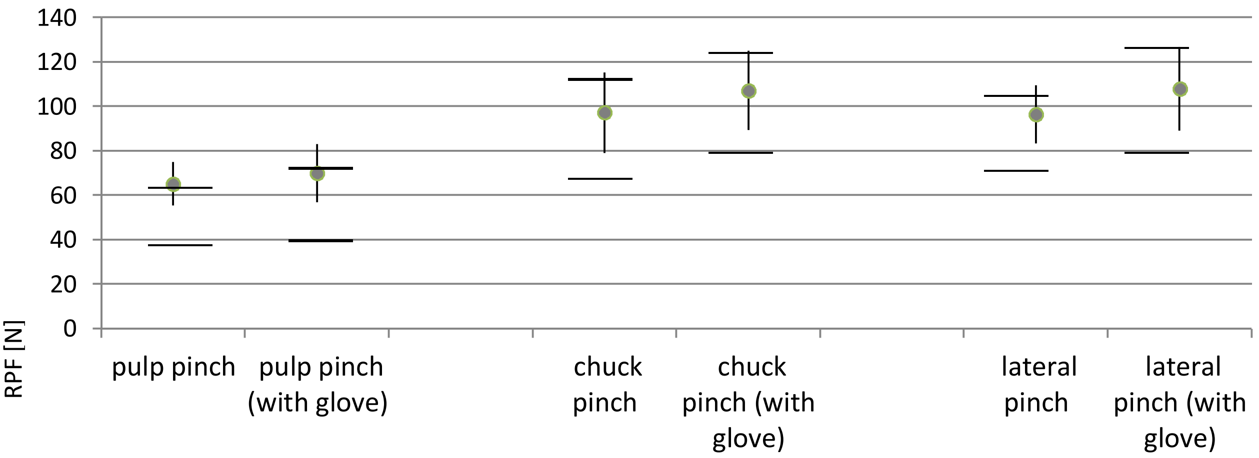

Fig. 10. Changes of RPF for all type of grasps in this study

3.2 The effect of the grasp width

Table 4 shows the mean and standard deviations for experiment 2. The results of the analysis of variance (ANOVA) for experiment 2 are presented in Table 5. MPF as well as RPF were not affected significantly by the width of the grasp for this experiment. It should be pointed out that these results correspond only to a 35 mm and 50mm width for pulp pinches and lateral pinches. Furthermore, it must be noted that this effect was not analyzed with gloves.

Table 4
The mean and standard deviations for experiment 2

Type of grasp	Dimension	MPF ± standard deviation [Newton]		RPF ± standard deviation [Newton]	
pulp pinch	35 mm	50.1	± 11.1	65.2	± 9.8
	50 mm	53.6	± 13.2	66.5	± 13.9
lateral pinch	35 mm	71.60	± 12.8	96.4	± 13.1
	50 mm	71.4	± 16.7	91.6	± 19.5

Table 5
Analysis of variance (ANOVA) with repeated measures for MPF and RPF (N=26)

Aim Source	df	MSE	F	P-Value
Repeated measures for MPF				
Within subjects:				
Type of grasp	1.000	10031.984	64.871	0.00*
Wide of grasp	1.000	69.259	0.739	0,398
Repeated measures for RPF				
Within subjects:				
Type of grasp	1.000	20556.691	106.014	0.00*
Wide of grasp	1.000	76.731	1.118	0,300

0,05 significance level(*).

3.3 The effect of the type of coupling

Table 6 presents the means and standard deviations for MPF and RPF for experiment 3. The results of the ANOVA (Table 7) show that the MPF and RPF for both the form fit and friction fit during the lateral pinch are affected significantly by the type of coupling. The form fit achieved a higher MPF than the friction fit. The RPF was lower whenever the subjects used the form fit compared to the friction fit. In contrast, the wearing of a glove had no significant effect on either of these forces. Furthermore, there is an interaction effect for only the MPF between the type of coupling and wearing or not wearing a glove. Fig.11 shows that the MPF increased by using the form fit, whenever the subject wore a glove. MPF reduced by the simultaneous use of the friction fit and wearing a glove. The value of RPF increased as seen in Fig.12 for both the form fit and friction fit, whenever the subjects wore a glove. Note that these increases had different gradients (slope).

Table 6
The means and standard deviations for MPF and RPF for experiment 3

	Type of coupling	MPF ± standard deviation [Newton]		RPF ± standard deviation [Newton]	
Without glove	Friction fit	71.6	± 12.8	96.4	± 13.1
	Form fit	129.5	± 25.2	90.2	± 22.4
With glove	Friction fit	58.0	± 14.2	108.0	± 18.8
	Form fit	140.7	± 31.1	95.8	± 24.1

Table 7
Analysis of variance (ANOVA) with repeated measures for MPF and RPF (N=26)

Aim Source	df	MSE	F	P-Value
Repeated measures for MPF				
Within subjects:				
Type of coupling	1.000	128372.402	291.76	0.00*
Glove	1.000	39.883	0.226	0.638
Interaction between type of coupling and wearing of glove	1.000	4015.657	24.551	0.00*
Repeated measures for RPF				
Within subjects:				
Type of coupling	1.000	2210.008	16.622	0.00*
Glove	1.000	1927.550	15.174	0,001*
Interaction between type of coupling and wearing of glove	1.000	232.322	2.914	0,1

0,05 significance level(*).

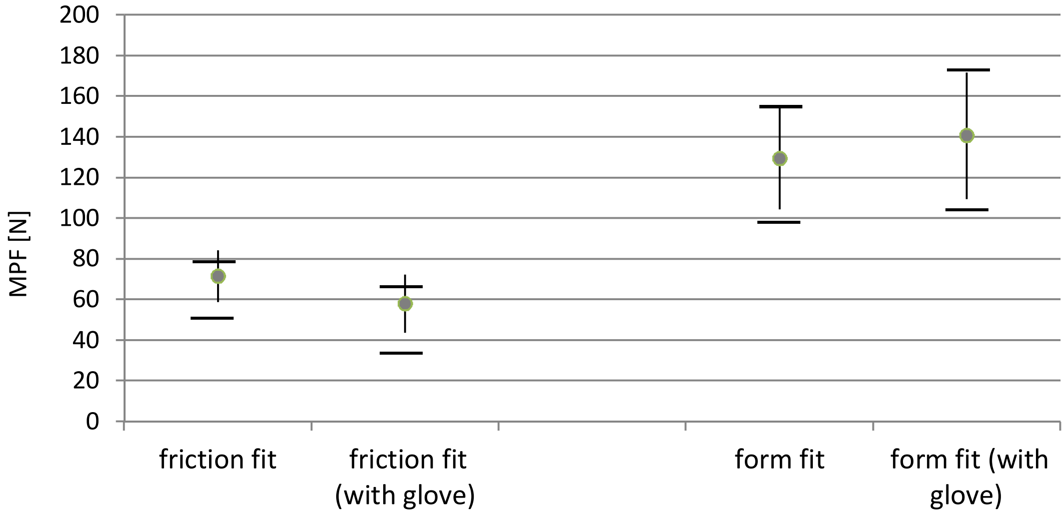

Fig. 11. Changes of MPF for both types of Coupling in this study

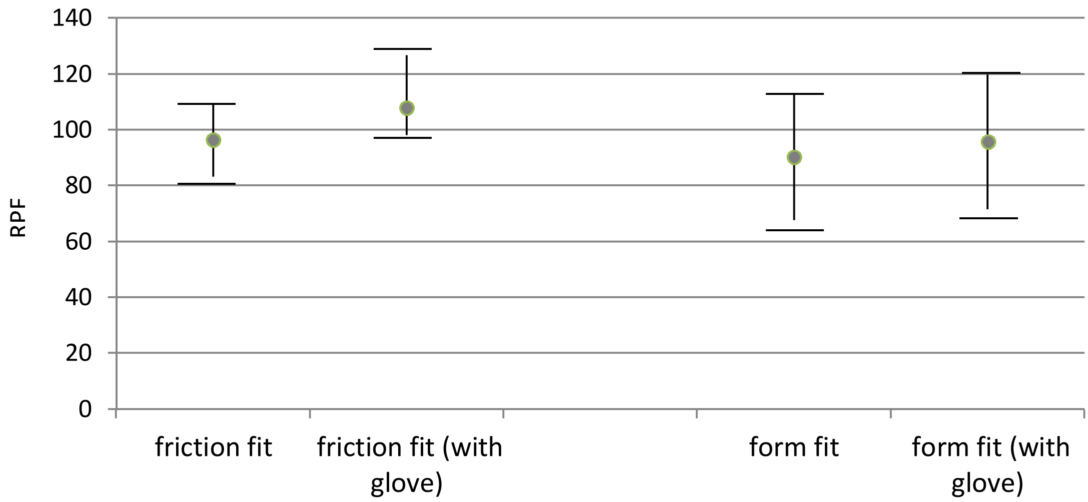

Fig. 12. Changes of RPF for both types of Coupling in this study

4. Discussion

The advantage of the measuring methodology in this study is that it simultaneously collected maximal pushing forces and required pinch forces for different grasp conditions. This methodology has not been reported in the literature. However, the results of this study were compared to the previous studies (as far as possible). Then the predications of results will be explained.

4.1 The results of this study compared to previous studies

The lack of research in the field of combined forces for different grasp conditions was indicated in the introduction. It must be pointed out that we can compare a part of experiment 1 and experiment 2 with previous studies (Table 8). However, we have not found comparable studies for experiment 3.

Table 8
Comparison of results

			Greig and Wells		Wakula		Potvin	
Type of grasp	MPF	RPF	MPF	MGF	MPF	MGF	MPF	MGF
pulp pinch	50.2	65.2			-	-	28.2	-
chuck pinch	64.6	97.4	96.4	107.3	-	106.0	-	-
lateral pinch	71.7	96.4	104.9	89.1	-	111.0	41.7	-

All Values in table are in [N]

The published values for maximal isolated forces during pushing according to Greig et al (2004) are generally higher than our results for MPF in both lateral pinch and chuck pinch. This difference can be explained by the effect of the friction coefficient. The contact surfaces of our dynamometer were plastic coated, but Greig et al. covered their dynamometer with athletic tape. The values of the MPF of the present study are higher than values published by Potvin et al (2006). The smaller values of the MPF in Potvin's research were caused by the specific population group, namely women. The maximal grasp forces (MGF) obtained from Greig et al and Schaub et al (2010) are not comparable with our results for the RPF. Therefore, the experimental conditions are completely different.

4.2 Predications of results

Based on the results of experiment 1, it can be pointed out that an increase in MPF (22%) and RPF (33%) occurs for the pulp pinch compared to the chuck pinch (Table 9). A possible reason for this increase is the involvement of more muscles during the chuck pinch compared to the pulp pinch. Moreover, the MPF and RPF during the chuck pinch are distributed between the proximal inter-phalangeal joints (PIP joints) of the index finger, middle finger and thumb. The distribution of forces during the pulp pinch is only between the PIP joints of the index finger and thumb. Additionally, the MPF and RPF increased 30% and 33% respectively. Whenever possible, the subjects used the lateral pinch instead of the pulp pinch. This is due to the fact that the index finger can be supported by other fingers on the side during the lateral pinch. In contrast, the index finger could not be supported due to the force direction during the pulp pinch. Another result of experiment 1 is shown in table 9. The values of the RPF increased simultaneously as the values of the MPF decreased, for all types of grasps, if the subjects wore a glove during the force exertions. Due to the lower friction coefficient between the glove and contact surface of the dynamometer, subjects needed more force to avoid slipping during the push exertion. Because of existing sensomotoric feedback mechanism grasp force will increase in response to the slip and stabilize the object. (Johansoon and westling, 1987).

Table 9
Changes in MPF and RPF between two pairs of grasps

	Change in MPF	Change in RPF
pulp pinch > chuck pinch	+22%	+33%
Pulp pinch > lateral pinch	+30%	+33%
Chuck pinch > lateral pinch	+10%	+0%

The results of experiment 2 in our study can verify the results of Imrahn et al (1955). In addition, our results show that the MPF is not affected by the width of the grip. An equipment limitation limited the experiment to two dimensions (35mm and 50 mm). Particularly in snap fit assembly, smaller dimensions have more relevance. Unfortunately, we could not adjust our dynamometer to smaller dimensions.

The results of experiment 3 can explain how and why the type of coupling affects the MPF and RPF. The use of the form fit led to an increase of 140% and 80% in MPF by wearing or not wearing a glove respectively. In contrast, the friction fit affects the magnitude of the MPF positively. The reason for this effect might be a better force transfer during the form fit compared to the friction fit. The form fit enables the subjects to bear their index finger in the cavity of the dynamometer.

5. Conclusion

The present study has shown that the magnitude of the MPF and RPF is affected significantly by the type of grasp, the type of coupling and the use of a glove. Table 10 shows the ratio of MPF to RPF for all measured values in this study. The optimal situation was obtained when the MPF increased and RPF decreased. So the Maximum value of ratio refers to optimal condition and the Minimum value of ratio refers to a suboptimal grasp condition. The largest value of ratio was obtained for the form fit during the lateral pinch with a glove and the smallest value of ratio was obtained during chuck, lateral and pulp pinch with glove. The wearing of glove has appositive effect on form fit condition and it has a negative effect on friction form grasp conditions. These results can be considered in both construction of snap-fits and organization of work.

Table 10
The ratio of MPF to RPF for all experimented grasp conditions

The experimented Grasp conditions	The Ratio of MPF/RPF
Pulp pinch, without glove , 35 mm	0.768405
Pulp pinch, with glove , 35 mm	0.557143
chuck pinch, without glove , 35 mm	0.662898
chuck pinch, with glove , 35 mm	0.521901
Latheral pinch, without glove , 35 mm	0.742739
Latheral pinch, with glove , 35 mm	0.537037
Pulp pinch, without glove , 50 mm	0.806015
Latheral pinch, without glove , 50 mm	0.779476
Form fit , without glove , Latheral pinch	1.435698
Form fit , with glove , Latheral pinch	1.468685

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