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ORIGINAL ARTICLE

Study of the Grasp Conditions Effects on Pinch-Insertion Force Using Wavelet Transform

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ABSTRACT

In this paper, the effects of different grasp types, grasp widths, coupling types, and wearing gloves on pinch-insertion force have been studied using the discrete wavelet transform method, which was proposed for extracting features from the force-time curves during the experiment that simulates the snap-fit assembly procedure. This paper uses collected Salmanzadeh and Landau [4] experiments data as an application for proposed methodology. This method allows to use of all information obtained from the experiment and considers the whole force exertion process instead of one point of curves and at the same time reduce the number of variables without losing information. The results obtained by applying multivariate analysis of variance (MANOVA) on the wavelet coefficients are more sensible and more precise than the results of the conventional method based on only one point of the curve. The results show that both wearing glove and grasp type significantly affect the pinch-insertion forces. The second series of results show that the effects of both grasp width and grasp type on pinch force are significant. The third result series show that both pinch-insertion forces are significantly affected by coupling type with/without wearing gloves. Further analysis was performed on the average wavelet coefficients curves that can explain the cause of MANOVA test results. The results of this paper can be used for ergonomic designing of snap-fits to reduce the potential damage of the assembly process.

KEYWORDS: *Grasp condition; Wavelet transform; Pinch force; Insertion force; Snap-fit*

INTRODUCTION

Snap-fit is an effective method of assembling plastic parts without extra fastener adhesive or welding operations. The cost of secondary components and the related operations (labour cost) is eliminated in this method [1]. Therefore, the use of snap-fits is more favoured in the industry, particularly in the automotive industry. Hübner's (2006) study, presented in the work of Landau, Landau [2] stated that more than 20% of vehicle fasteners are snap fits

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components. Despite these advantages of snap fits, some ergonomic aspects should be considered in the design of snap-fits, as they are usually the case.

One of these aspects is the insertion forces required for the interlocking of snap fits. The insertion of snap fits sometimes requires relatively high forces on the hands and fingers due to the limited dimensions of some snap fits, and it demands a particular grasp type. The maximal acceptable forces for the insertion of snap-fit for three different grasp types (pulp pinch, lateral pinch and finger press) and different frequency conditions were investigated by Potvin, Calder [3]. Although they ignored the pinch forces exerted during the insertion process [4].

High precision-pinch grip exertions have been related to fatigue, discomfort and the development of various hand-related Cumulative Trauma Disorders (CTDs) in industrial populations [5-9]. Pinch strength data for adults in different age groups have been studied by some researchers like Mathiowetz, Kashman [10] and Peebles and Norris [11].

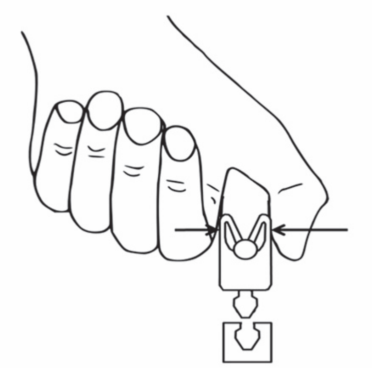

Fig 1. Use of pinch force during the insertion of fasteners

Lee and Jung [12] have studied the objects' shapes, size and direction common patterns of grasp types. The influence of some other factors such as gender, body posture, wrist position, repetition, object width, and shape on maximal acceptable pinch forces have also been studied by several authors [13-19].

For the Snap-fit assembly, the insertion (push) forces affect the interlocking process directly and productively, and while the pinch (grasp) forces are not productive, they are required to accomplish the assembly process (figure 1). Therefore, a minimum required pinch force for a maximum insertion force is desirable. On the other hand, an insufficient grip force during insertion of snap fits can result in hand slippage leading to a hand injury [20]. The investigation of the relationship between maximum insertion forces and the minimum required pinch forces during the snap-fit assembly is essential for reducing fatigue and injuries. The simultaneous occurrence of these forces has not been sufficiently studied in the literature. Seo [21] has examined the relationship between the safety margin and the insertion force so that the safety margin has been defined as the difference between voluntary and grip forces. Seo [21] focused on the lateral pinch while in other grasp types, coupling types, the effect of gloves and the width of grasping have not been considered.

Salmanzadeh and Landau [4] have defined the mentioned factors above as grasp conditions and studied their effects on maximal acceptable insertion forces and the minimal required pinch forces. They have used only the maximum amount of insertion force and the projected pinch force from each force-time curve for analyzing these effects. However, the force-time curves provide more information that refers to the behavioural force exertion pattern. Studying only one point of this curve does not examine all features of the forces. In this paper, we present a method that has combined wavelet transform and Multivariate Analysis of Variance (MANOVA) to use all the features of force-time curves.

In this study, real data is used, which is very noisy and has high dimensions. Because data is acquired from sensors that have recorded subject's force during specific time interval, and the sensors were very sensitive, so they recorded even very small fluctuation of inserted forces. This data is generated by measuring the forces applied by operators. For each person, 1000 records were gathered for insertion force and corresponding pinch force. Due to high fluctuation in data, an efficient method is required for analyzing them. Wavelet is a mathematical method used for denoising, curve fitting, feature extracting, and reducing the dimension of different data. Since data in this research is big and too noisy, we suggest a robust method called Discrete Wavelet Transform (DWT) to denoise and extract all useful information from the force-time curves.

In recent decades, the wavelet method has become one of the important tools in various engineering fields. There are many methods based on wavelet transform that can be used for data analysis. Liu, Sun [22] presented a heuristic wavelet shrinkage for denoising. Qu, Adam [23] used wavelet for dimension reduction in high dimensional data. Wavelets have many applications in signal analysis and image processing [24-26]. However, this method has been rarely used in ergonomic applications. These applications are mostly relevant to EMG (Electromyography) signal analysis [27-31].

In this paper, we have used wavelet transformation to reduce the dimension of recorded data of our experiments and then applied multivariate analysis of variance to test the effect of the different type of grasping (pulp, chuck and lateral), different grasp width, different type of coupling and wearing glove on insertion and pinch force. The result of this paper can help ergonomic engineer to design snap-fits ergonomically so that it reduces the possible damages during assembly procedure.

MATERIALS AND METHODS

Experiment:

This paper uses the collected data from Salmanzadeh and Landau [4] experiment, and the experiment's procedure is explained briefly in this paper. As mentioned in the introduction, several studies in the literature refer to the effect of the factors such as gender, age, hand-arm position and the flexion of hand on insertion and pinch forces. To control the interference factors and obtain reproducible results, a proper design of an experiment's procedure and condition was adopted by Salmanzadeh and Landau [4] so they selected a unique subject population for the experiments.

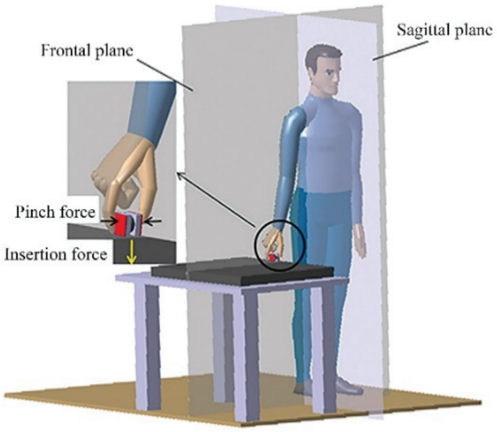

Fig 2. Pinch and insertion force exertions with dynamometer and force plate on an adjustable height desk

26 male students between the ages of 20 and 30 participated in the study. All participants were in a good constitution and had no history of upper limb pain or musculoskeletal disorders. All standard deviations for the anthropometrical dimensions of the subjects' hand did not exceed 10 percent of the related mean dimension. The summary of subjects' anthropomorphic data is presented in Table 1. The height of the desk was adjusted to the subjects' stature so that each experiment set was executed for all subjects in the same Hand position (neutral zero position of the whole body). Figure 2 demonstrates how the insertion forces were obtained using a non-slip force plate (Krag SWISS 9162A) on the height-adjustable desk, and the pinch forces were obtained by a dynamometer (Kistler type 9117A1.5). Also, we have considered the difference of friction coefficient between wearing glove and normal states in our paper. The friction coefficient between hand and clips is 0.4 and 0.29 for normal and wearing glove states, respectively. These measures are obtained by dividing shear force on contract force.

Table 1. Anthropomorphic data of participants' fingers (mm)

	Thump length	Thump breadth	Index length	Index breadth	Finger span
Mean	6.91	2.36	8.16	1.86	15
Standard deviation	0.66	0.17	0.69	0.16	0.89

For obtaining insertion forces, subjects had to press the dynamometer with their maximum voluntary forces for about 6 seconds, suggested by Kroemer [32], on the force plate as long as they could. Simultaneously, the subjects were asked to exert the required pinch force to hold and execute the insertion force without slippage on a dynamometer. The related pinch forces during the insertion forces were collected for each subject. Figure 3 demonstrates an example of force-time curves, which were generated in the experiments.

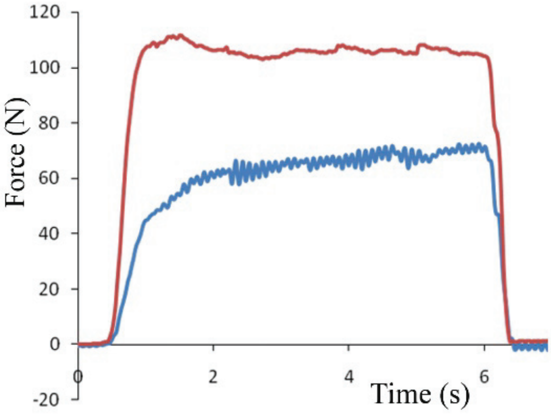

Fig 3. An example of Force-time curves collected in the experiments.

Subjects executed the forces in groups of 3 or 4 people to have enough time (2 minutes) to recover their force after each force exertion for the next force exertion. Each subject had to repeat the same test three times for statistical reliability. All different tests, which will be explained below, were executed randomly to control the motivation effect. For controlling the grasp condition, subjects were asked to be careful about the test procedures and especially avoid supporting their fingers on the top of the dynamometer.

Four grasp conditions (grasp type, grasp width, coupling type, and wearing a glove), which refer directly or indirectly to the geometrical and material characteristic of snap fits, were selected in the experiments. Each of these conditions has two (grasp width: 35mm and 50 mm, coupling type: friction-fit and form-fit, gloves: using and not using gloves) or three characteristics (grasp type: pulp pinch, chuck pinch and lateral pinch).

In a classical experiment design, we should consider all combinations of conditions with their corresponding characteristics. The number of all these combinations for the 26 participants amounts to 624 tests, which is very time consuming and cost intensive. Therefore, some combinations during the three experiments series were systematically selected to execute 260 tests.

In the series of the first experiments, the insertion and related pinch forces were collected for three grasp types (pulp pinch, chuck pinch and lateral pinch), with and without gloves (figure 4). The grasp width was not a test factor in this experiment, and its size was 35 mm. In total, six experiments were executed for each subject in this step.

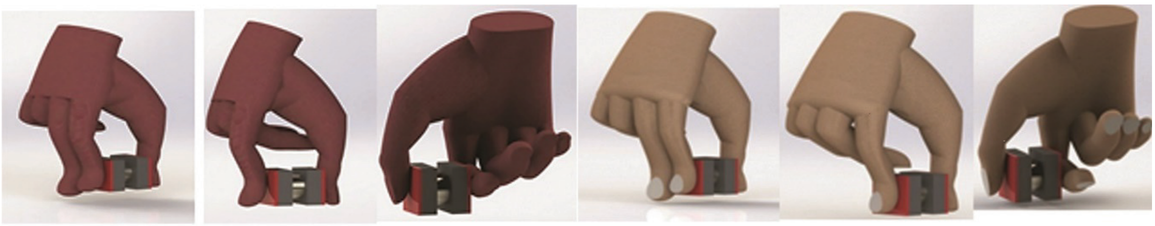

Fig 4. Different grasp conditions in the first experiment series from right to left (lateral pinch, pulp pinch, chuck pinch without a glove and lateral pinch, pulp pinch, chuck pinch with glove all in the wide of 35 mm)

The second experiment series' focus was the study of grasp width's effect. As the data for the width of 35 mm in the first series of experiments had already been observed, the insertion and related pinch forces were observed only for the grasp width of 50mm. Furthermore, only two grasp types (pulp pinch and lateral pinch without glove) in the grasp width of 50 mm were selected for the second experiment. A total of four experiments' data was used for the analysis of this experiment series as two experiments were executed for each subject in this step including pulp pinch, lateral pinch for 35mm width and pulp pinch, lateral pinch for 50mm width (figure 5).

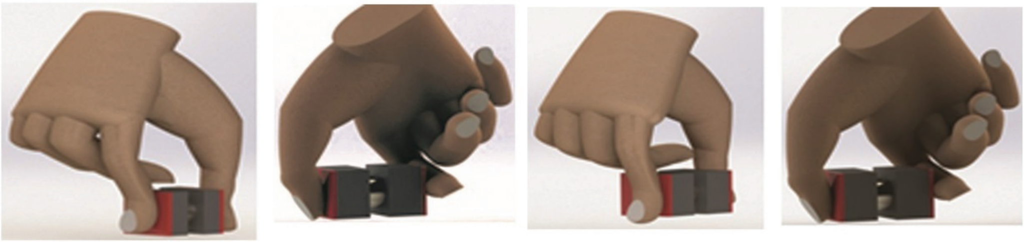

Fig 5. Different grasp conditions for the analyzing in the second experiment series from right to left (lateral pinch, pulp pinch in the wide of 35mm and lateral pinch, pulp pinch in the wide of 50mm both without glove)

The third series of experiments aimed to collect data for the insertion and related pinch forces for two coupling types (friction-fit and form-fit), each with and without gloves. Since the effect of the form-fit coupling on the two types of grip (pulp pinch and chuck pinch) is low, only the lateral pinch was selected for the data collection and analysis. The selected size for the grasp width was 35 mm in this step. Totally, four experiments' data were used for the analysis in this step (figure 6).

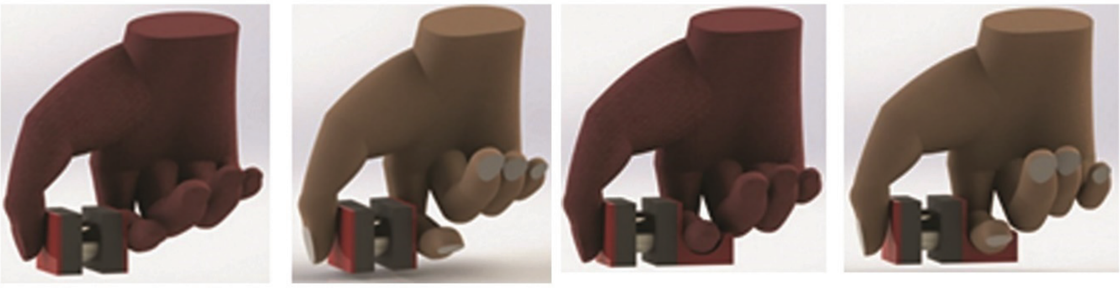

Fig 6. different grasp conditions for the analysis in the third experiment series from right to left (form-fit without a glove, form-fit with a glove, friction-fit without a glove, friction-fit with glove all in the wide of 35mm and a lateral pinch)

Wavelet Shrinkage:

Real-world data rarely come clean. In order to extract useful information from raw data, a theoretically sound and robust denoising method is often required [33]. Our data in this research is big and noisy, and a robust method is required for cleaning, denoising and extracting useful information from it. Therefore, the Discrete Wavelet Transform was chosen for data analysis, cleaning, denoising and extracting useful information.

Suppose that $y(t)$ is an observed signal in time series with length n which is represented as

$$y(t) = a(t) + d(t)\,; \qquad t = 1,2,\dots,n \qquad (2\text{-}1)$$

Where $a(t)$ and $d(t)$ are basic signal and additive noise, respectively. Generally, there is no available information about $a(t)$ and $d(t)$. Applying DWT on the signal is decomposed into two parts $a(t)$ and $d(t)$. This method transforms data from each space to frequency space with the same properties. The DWT of signal y(t) is calculated by passing it through two filters. First data is passed through a low-pass filter, and second data is passed through a high-pass filter. The first filter output is approximation coefficients, and the second filter outputs are detail coefficients (figure 7).

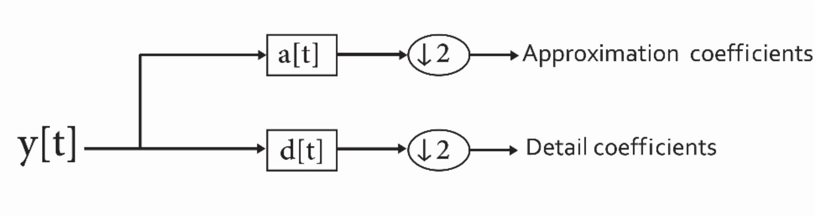

Fig 7. Diagram of low-pass and high-pass filter

This procedure can be repeated several times. The wavelet transform can be applied to coefficients approximation again. Half the frequency of the signal will be removed each time to have a higher resolution. Therefore, the equation (2-1) can be rewritten as

$$y^j(t) = a^{j_0}(t) + d_{j_0}(t) + \cdots + d_1(t)\,; \qquad t = 1,2,\ldots,n \qquad (2\text{-}2)$$

Where j_0 is resolution level. Instead of the original signal, approximation coefficients and the sum of detail coefficients from resolution level 1 to j_0 can be used. Depending on the type of analysis, the detail coefficients can be ignored at each level. Thus, further analysis can be applied to approximation coefficients, which is simpler than the original signal. In this section, a general discussion about wavelet transformation is explained, and the mathematical calculation of the wavelet transform will be explained in section (2.3).

Wavelet Transform:

Wavelet transform is a tool for approximating complex functions with local properties such as non-differentiable and variable frequencies. Using the wavelet transform can describe a complex function as a linear combination of wavelet basis functions. For better understanding, consider an obtained signal in a time series with length n represented as $y(t)$ $(t = 1,2,\ldots,n)$. The Continuous Wavelet Transform (CWT) of $y(t)$ can be de fined as follows

$$C(a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} y(t)\psi(\frac{t-b}{a})dt \qquad (2\text{-}3)$$

Where a and b are scale and location parameters respectively. $\psi(t)$ is a wavelet mother function. One of the most important wavelet mother functions is "*Haar*" which is used in this research too. The Haar wavelet function is defined as follows

$$\psi(t) = \begin{cases} 1 & 0 \le t \le 1/2 \\ -1 & 1/2 \le t \le 1 \\ 0 & o.w \end{cases} \qquad (2\text{-}4)$$

A wavelet transformation which calculates only certain value of scale and location parameters is called Discrete Wavelet Transform. DWT is mainly computed in $a = 2^{-j}$ and $b = k2^{-j}$ for integer value of *j* and *k*. Therefore, wavelet child, $\psi_{jk}(t)$, is

$$\psi_{jk}(t) = \sqrt{2^j}\psi(2^j t - k); \quad j,k \in Z \qquad (2\text{-}5)$$

Then, DWT of $y(t)$ on the scale of $2^j$and in the location of $k2^{-j}$ is defined as follows

$$C_{jk} = \int_{-\infty}^{+\infty} y(t)\psi_{jk}(t)\,dt = \langle y(t), \psi_{jk}(t)\rangle \;;\; j,k \in Z \qquad (2\text{-}6)$$

In fact, the DWT of a signal on a scale of $2^j$and in the location of $k2^{-j}$ calculates the similarity of the signal with the wavelet child function. It can be shown that an integrable square signal is a linear combination of the wavelet child, thus

$$y(t) = \sum_{j\in Z}\sum_{k\in Z} c_{jk}\,\psi_{jk}(t) \qquad (2\text{-}7)$$

Where c_{jk}s are wavelet coefficients.

There is a wavelet father function or scaling function corresponding to each wavelet mother function, which is indicated as $\phi(t)$. we can express signal $y(t)$ under some assumption as follows

$$y^j(t) = \sum_{-\infty}^{\infty} c_{jk}\phi_{jk}(t) \tag{2-8}$$

Where $c_{jk} = \langle y(t), \phi_{jk}(t)\rangle$. According to the definition of scaling function, it can be shown that

$$y^j(t) = \sum_{-\infty}^{\infty} c_{j-j_0k}\phi_{j-j_0k}(t) + \sum_{i=j-j_0}^{j-1}\sum_{k=-\infty}^{\infty} d_{ik}\,\psi_{jk}(t) \tag{2-9}$$

Where j_0 is the resolution level. As is clear, equation (2-9) is equivalent to equation (2-1). The first term of equation (2-9) is an approximation of signal $y^j(t)$ in resolution level j_0 and the second term is details of signal $y^j(t)$ in resolution level i. In equation (2-9), c_{ik} and d_{ik} are calculated as follows

$$c_{ik} = \langle y(t), \phi_{ik}(t)\rangle$$
$$d_{ik} = \langle y(t), \psi_{ik}(t)\rangle \tag{2-10}$$

Here, we provided an example for wavelet decomposition of a force signal generated in five levels (figure 8). As it can be seen, the original signal, S, is decomposed into six separate signals, where a_6 is approximation of the original signal and d_1,d_2,...,d_5 are detailed signals so their sum equals the original signal.

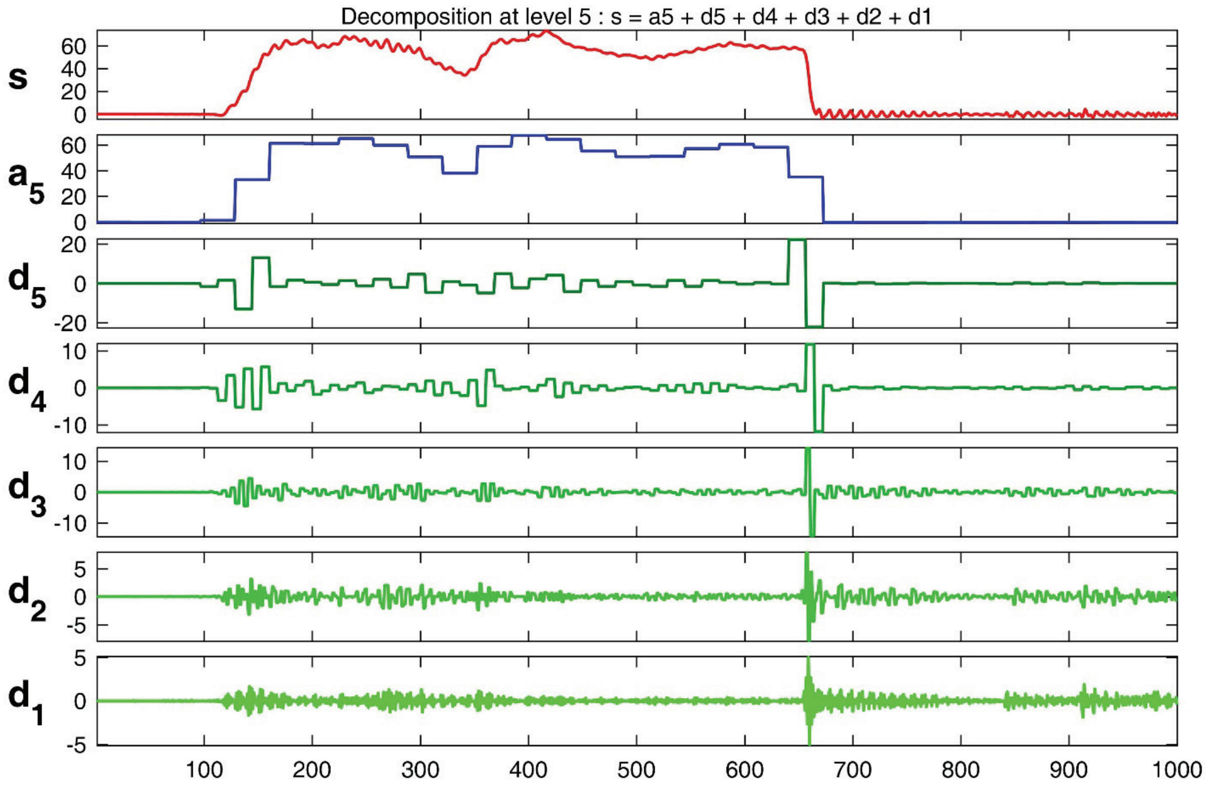

Fig 8. Wavelet decomposition of the force signal

RESULTS

Various types of grasping and coupling are tested statistically to explain their difference. For this purpose, the wavelet coefficients have been calculated in level 5, and then the MANOVA test was performed on the 32 wavelet coefficients. Since wavelet coefficients are orthogonal to each other, MANOVA will lead to the correct results.

There is potential for comparing coefficients one by one by post hoc analysis. However, this analysis is confusing due to the number of variables and factors impacting them. For this reason, instead of post hoc analysis, the charts of average wavelet coefficients for all grasp types are presented in this paper. These charts provide a detailed perspective of the whole insertion/pinch force exertion process.

The effect of grasp type and glove:

Here, we test the effect of three grasp types: pulp, chuck and lateral, and wearing gloves during the manual insertion process. As mentioned, the results consist of two parts in Table 2. The first part includes MANOVA for pinch force, and the second part includes MANOVA for insertion force.

As shown in Table 2, both wearing gloves and grasp type significantly affect the insertion and pinch forces. There is also an interaction between grasp type and the wearing of gloves. In the second part of the results table, the charts of wavelet coefficients were presented as the representative for force exertion processes.

Table 2. The results of the MANOVA test for grasp type and glove (significance level of 0.05)

Force Type	Source of Changes	D.F	F	P-value
Pinch Force	Grasp type	64	9.530	0.00
	Wearing Gloves	32	7.600	0.00
	Interaction	64	3.240	0.00
Insertion Force	Grasp type	64	4.252	0.00
	Wearing Gloves	32	9.062	0.00
	Interaction	64	3.347	0.00

As the coefficients' chart for insertion force shows, the amounts of coefficients of forces in the chuck and lateral grasping, whether with or without gloves, are approximately equal. However, they are more significant than pulp grasping (figure 10). Comparing coefficients of insertion forces also shows that in all three grasp types, the coefficients' values have significantly declined in terms of wearing gloves compared to similar cases without gloves, and the amount of this reduction occurs more in pulp grasping. A similar situation occurred in the chart for coefficients of pinch forces. The corresponding values

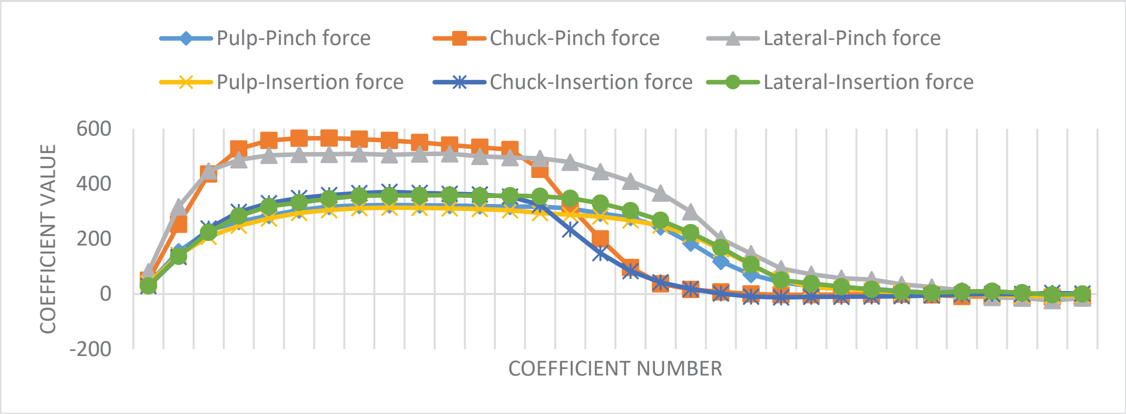

Fig 9. Comparing the average wavelet coefficients of pinch forces with and without gloves for different grasp type (Pulp, Chuck, Lateral)

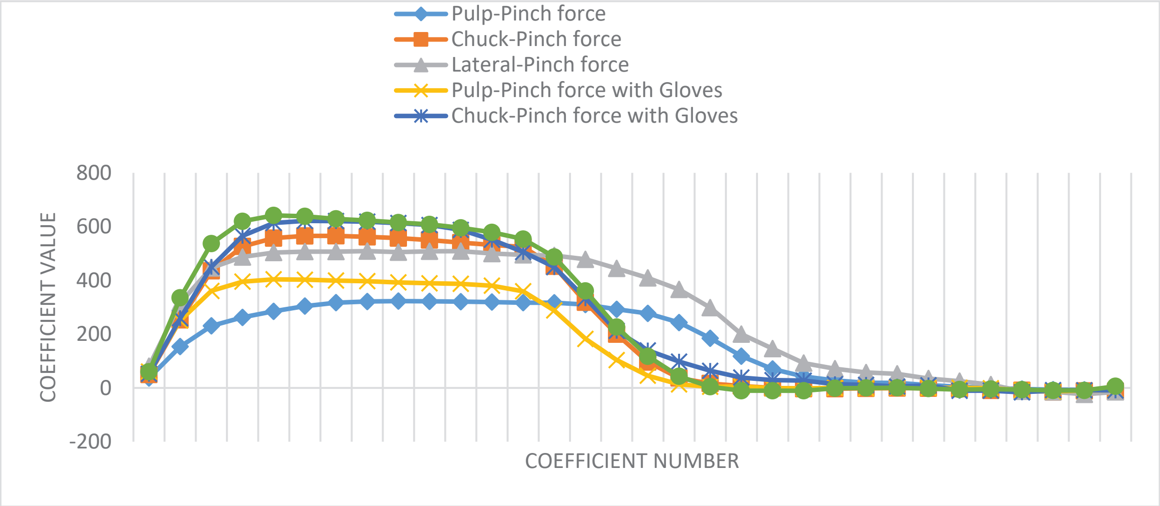

Fig 10. Comparing the average wavelet coefficients of insertion forces with and without gloves for different grasp type (Pulp, Chuck, Lateral)

of chuck and lateral grasping are greater than pulp grasping, and wearing gloves increases the values in all types of pinch grasping, and this increase is more tangible in pulp grasping (figure 9).

The effects of grasp width and grasp type:

The second test data is used to explore the effects of grasp width on the exerted force in two grasp types. For this purpose, two distances for dynamometer width (35mm and 50mm) are considered, and the measured forces in two grasp types (pulp and chuck) are used. Therefore, there are two factors in this stage: the first factor is grasp width, and the second is the grasp type. The results are shown in Table 3. As is apparent, there is no interaction between factor distance and grasp type for both pinch forces and insertion forces. Table 3 shows that both effects of grasp width and grasp type in pinch forces are significant. However, the insertion force is only affected significantly by grasp type.

The coefficients' chart of grasp width shows that the insertion forces in the whole process for lateral grasping of the width of 50mm is surprisingly more than the width of 35mm while corresponding pinch forces are almost the same for the two widths in lateral mode, and this is reverse for pulp grasping. Thus, insertion forces in most of the pulp grasping processes with the width of 35mm are more than the width of 50mm (figure 12). The charts for coefficients of pinch forces of the pulp grasping show that the value of coefficients in the width of 50mm is again more than the case with the width of 35 mm (figure 11).

The effects of coupling type and glove:

In this part, the effects of two coupling types (friction-fit and form-fit) have been tested in lateral grasping and wearing a glove. As described in this experiment, we have two types of coupling. In type one, each subject grasps a dynamometer in the lateral pinch posture in friction-fit coupling. In the second type, subjects exert the force by leaning the index finger on a cavity designed on one side of the dynamometer in form-fit coupling. Table 4 shows the results of the MANOVA Test for wavelet coefficients of insertion and pinch forces for two different couplings with and without wearing gloves, respectively. Both forces are significantly affected by coupling type with and without wearing gloves. There is also an interaction between coupling type and the wearing of gloves.

Furthermore, the coefficients' chart of insertion forces in both coupling types show that their values in form-fit coupling are more than friction-fit coupling. However, wearing gloves leads to an increase in values for coefficients of insertion forces in the form-fit grasping even more than the case without gloves (figure 14). The charts for coefficients of pinch forces in both coupling types do not show any significant difference in the case of no glove, while the values of coefficients for pinch forces in friction-fit coupling are more than in the form-fit coupling (figure 13).

Table 3. The results of the MANOVA test for grasp type and grasp width (significance level of 0.05)

Force Type	Source of Changes	D.F	F	P-value
Pinch Force	Grasp Width	32	1.637	0.020
	Grasp type (Pulp & Chuck)	32	9.735	0.000
	Interaction	32	1.053	0.395
Insertion Force	Grasp Width	32	1.350	0.106
	Grasp type	32	2.346	0.00
	Interaction	32	0.723	0.865

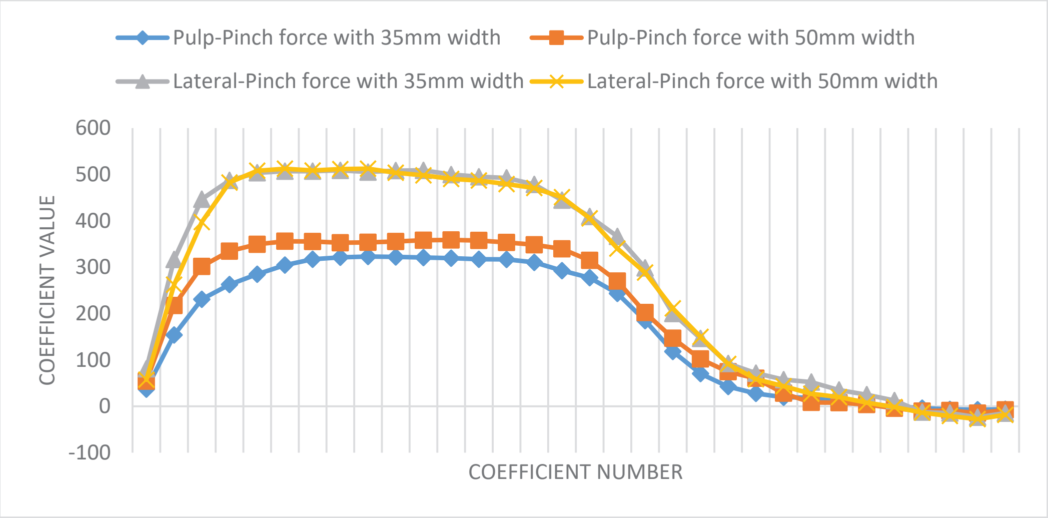

Fig 10. Comparing the average wavelet coefficients of pinch forces for different grasp width

Table 4. The results of the MANOVA test for coupling type and glove (significance level of 0.05)

Force Type	Source of Changes	D.F	F	P-value
Pinch Force	Coupling Type	32	3.218	0.00*
	Wearing Gloves	32	4.066	0.00
	Interaction	32	3.337	0.00
Insertion Force	Coupling Type	32	23.688	0.00
	Wearing Gloves	32	1.661	0.017
	Interaction	32	1.881	0.004

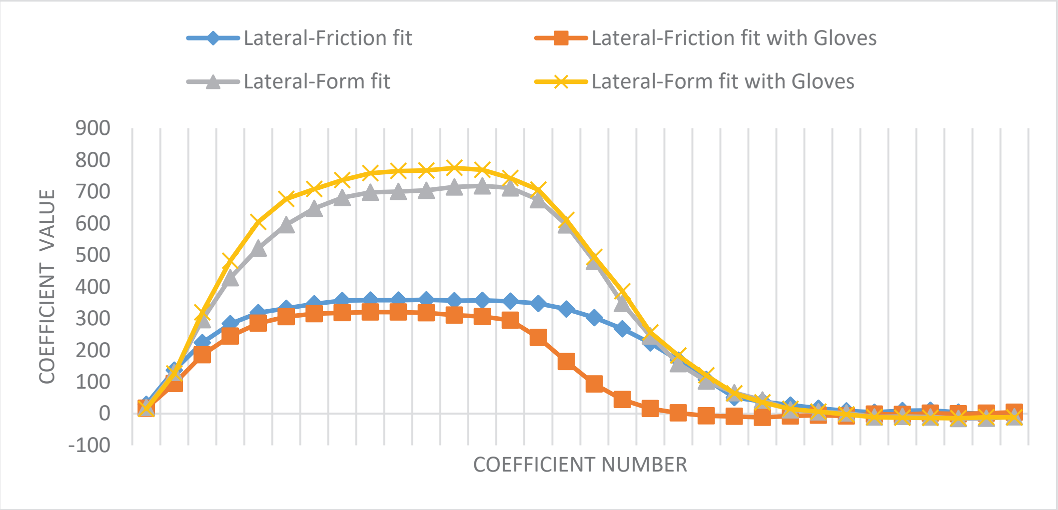

Fig 11. Comparing the average wavelet coefficients of insertion forces for different grasp width (35mm, 50mm)

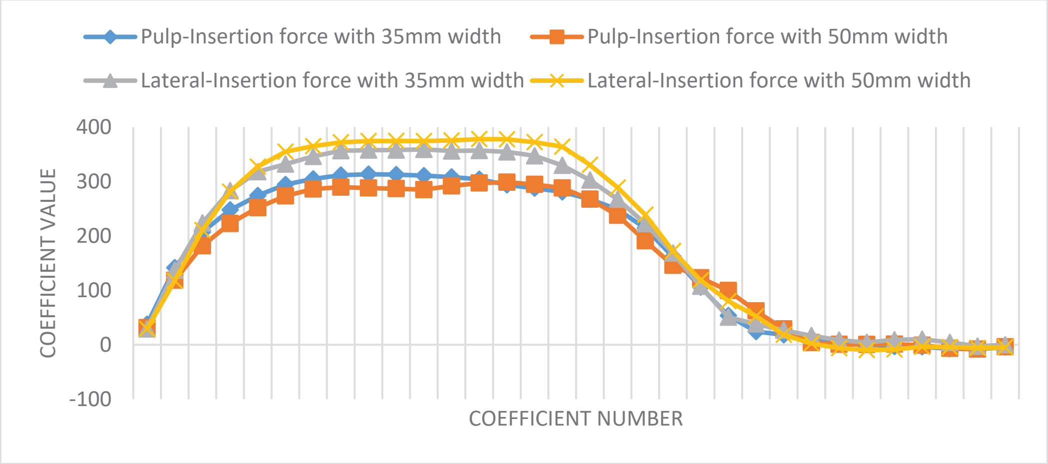

Fig 12. Comparing the average wavelet coefficients of pinch for different coupling type

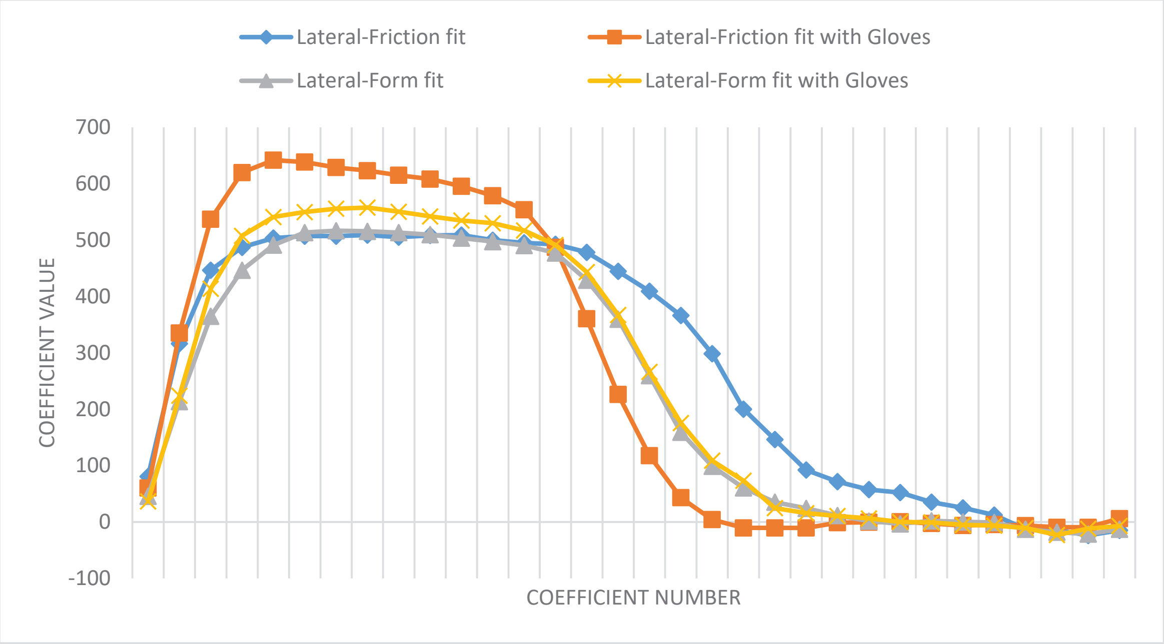

Fig 13. Comparing the average wavelet coefficients of insertion for different coupling type

DISCUSSION

To explain this paper's results, we have to consider it in two general separate parts, namely the MANOVA analysis and the charts of average coefficients for insertion/pinch force processes. The first parts' results are sensible for one of the coefficients in the whole force exertion process to be generally valid for the whole process. The results of the second part show more details about coefficients behaviour. To keep a clear view, the same schema as the previous chapter will be used for the following sections to discuss the results and compare them with those of Salmanzadeh and Landau [4] obtained by using only maximum points of force-time curves.

4.1 The effect of grasp type and wearing glove:

This paper's results and the results reported by Salmanzadeh and Landau [4] regarding the effects of grasp type and wearing gloves on insertion/pinch forces are both in the same direction. However, there is a difference between this paper's results and their study in the context of the interaction between grasp type and the wearing of gloves in both insertion and pinch forces for the entire curve. The reason for this contradiction is the use of a different method for analyzing curves in this paper so that it tries to use all available information and study the behaviour of forces over time. The charts of average coefficients also can explain the existence of interaction in some areas. It is useful to explain the cause of some changes in the force exertion process by studying these charts as follows.

The reason for the increased insertion forces and decreased pinch forces in wearing gloves could be the reduction of the friction coefficient in the case of wearing gloves. The curve's behaviour for pinch forces in wearing gloves and all three grasp types refer to a decrease in the peak of the curves. On the contrary, the curves' behaviour for the insertion forces in the pulp pinch case refers to an increase or stabilization in the peak term. This could be explained by probably more support of fingers in the top of the dynamometer for the compensation of slipping in the pulp pinch case.

The other tip that can be noted in the charts is early fall in the curves for pinch forces in chuck grasping, which indicates less stability of this grasp type (the maximum force can be inserted for a shorter time) than other grasp types. It can be considered in the design of clips.

4.2 The effect of grasp width:

The comparison between this paper's results and the results of Salmanzadeh and Landau [4] study represents different results for the effect of grasp width in pinch force. The effect has been significant in this paper, while it had not been significant in their paper. This indicates the wavelet method's power again that considers the whole force-time curve and explores this significant effect while using only one point of the curve was not available to detect it.

The study of the corresponding charts for average wavelet coefficients shown in the results section helps us explain the curves' behaviour. The higher values of wavelet coefficients for insertion forces in wider lateral grasping are due to the higher possibility of finger supporting on the dynamometer's top during the force exertion process. In contrast to the lateral grasping, the wider distance of the dynamometer cannot support fingers on the top of it. Since it cannot contribute to more stability in wider pulp grasping, it accounts for the higher values of coefficients for pinch forces in the wider pulp grasping. There is a combination of form-fit and friction-fit coupling in lateral grasping that cause a compensation effect in the curves' behaviour for pinch forces due to finger support.

4.3 The effect of coupling type

Regarding the effect of coupling type and wearing gloves, there is one difference between the results of this paper and the results of Salmanzadeh and Landau [4] study. They had not found any significant effects of wearing gloves on the maximum insertion force for this experiment. However, they had reported an interaction between coupling type and wearing gloves, as reported in this study's results.

The curves' behaviour of insertion/pinch forces in this experiment helps us recognize the reason behind differences regarding the couplings type and wearing of gloves. In friction-fit coupling by wearing the glove, the coefficients' curves of insertion forces are the lowest and the shortest one. The reason lies in the slippery contact surface and lack of support surface for the finger, unlike the form-fit coupling. Wearing the glove contributes to more slippery contact in friction-fit coupling than not wearing gloves. However, the wearing of the glove in form-fit coupling led to increased coefficient values of insertion forces. Because the subjects are enabled to support them outside of their forefinger on the cavity's surface, they achieve more stability. The contact surface is softer than the case without gloves.

The coefficients' curves of pinch forces without gloves are approximately unique during the whole force exertion process. This refers to less demand for the allocation of pinch forces in form-fit than the case of friction-fit. However, the fall of the curve in the case of friction-fit coupling occurs earlier than the case of form-fit coupling because of more slippery contact and less grasping stability.

The coefficients' values of pinch forces in the case of friction-fit with wearing gloves are more than the case of form-fit. In other words, a decrease in the curve for the case of friction-fit with wearing gloves has occurred because the subjects strained to keep the stability of grasping, but they had less energy at the end of the process.

CONCLUSION

This paper has focused on the ergonomic aspect of the snap fits assembly and studied the effects of grasp types, grasp width, coupling type, and wearing gloves on the force exertion process. The procedure of experiments and collecting data was explained. The detailed results of experiments are represented, and the significant effects were identified. Wavelet transform helps us by feature extraction to have a better analysis of the whole process so that we used 32 variables instead of 1000 variables (the total collected data in each experiment) and at the same time preserved all characteristics of 1000 variables. Using the multivariate ANOVA, this study could test the effects of different factors on the insertion/pinch forces during the whole force exertion process and the average wavelet coefficients curves for insertion/pinch forces different grasp conditions, which presented and assisted the declaration of differences in the whole process. In other words, we can claim that no information is lost, and the calculations are simplified. The proposed methodology has been applied on

Salmanzadeh and Landau [4] data to show the efficiency of the model.

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CONFLICT OF INTERESTS

There was no conflict of interest in this study.

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