An Assimilation of TRIZ in Dissecting the Statistical Outcomes of Tactile Sensitivity, Pinch Force and Endurance among Elderly People

Dominic Wen How Tan
Multimedia University
Poh Kiat Ng (npohkiat@yahoo.com.sg)
Multimedia University https://orcid.org/0000-0001-7995-8251
Ervina Efzan Mhd Noor
Multimedia University

Research

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Abstract

Background: Numerous investigations have analysed the handgrip force and endurance of elderly people. However, few studies examine reduced and increased tactile sensibility effects on the pinch force and endurance of elderly people. Even fewer studies include the problem-solving process extending from statistical outcomes of such studies. This study examines tactile sensibility effects on the pinch force and endurance of elderly people, and potentially resolves issues dissected from these inferences using TRIZ.

Methods: Data on pinch force and endurance time was collected among 32 subjects aged 55-65 years old. Subjects were required to pinch an experimental apparatus at their maximum limit, and sustain their pinching activity for as long as possible. Cotton gloves were for reduced tactile sensibility while rubber gloves were for increased tactile sensibility. The two-sample T-test results were further analysed using TRIZ.

Results: The results suggested that a significant difference existed between the pinch force from reduced and increased tactile sensibility ($p < 0.05$), with similar outcomes for endurance time. Resolving TRIZ contradictions identified from the results presented this study with a principle known as “partial action”, which suggested that elderly people should pinch using less of the originally desired force when the exact intended force is difficult to achieve, rather than exerting a high pinch force in a single attempt. The “segmentation” and “other way around” principles were also recommended. Through Su-Field analysis, it was found that harmful effects from pinching can be neutralised using intermediary materials between the fingers and object, such as rubber. The analysis also proposed using optical or acoustic fields, whereby light sensors or buzzers could act as mechanisms to provide signals once a sufficient pinch force is detected.

Conclusion: This study confirmed that elderlies with poor tactile sensibility commonly pinch objects with excessive force and extended durations. The inventive solutions that extend from this finding through TRIZ provide new insights to researchers in product design with the aim of resolving poor pinch performance caused by degrading tactile sensibility.

Background

As much as we want to stay young, age is never just a number as the human body changes every day. The United Nations define an elderly person as someone aged 65 years and above (World Health Organisation, 2016). With the increase of age, the pace of life starts to slow down because of the reduction in twitch tension and lower firing rate of motor units, which negatively affects overall muscle health (Duchateau & Hainaut, 1990).

It is forecasted that by the year 2020, a total of 3.3 million Malaysians will be above 60 years old (Mafauzy, 2000). This figure is concerning because elderlies tend to be less healthy than the younger population. They become more vulnerable to physical disabilities and mental illnesses (Kostopoulos, Kyritsis, Ricard, Deriaz, & Konstantas, 2018). Some of the significant health issues they face occur in their hands and fingers, for example, weakness in pinching and griping objects, which can even lead to carpal tunnel syndrome. According to Zhang and Niu (Zhang et al., 2002), osteoarthritis is also a common disease among elderlies which frequently impairs hand function.

In a longitudinal investigation of musculoskeletal impairments and their physical disabilities, findings confirmed that physical disabilities are significantly caused by musculoskeletal degradation (Jette, Branch, & Berlin, 1990). There are recorded examples of poor hand functions in particularly basic activities of daily living. For instance, it was found that many elderlies have trouble opening or unscrewing the caps of bottles, especially those from medicine containers (Rahman, Thomas, & Rice, 2002; Rice, Leonard, & Carter, 1998). In association to this issue, one of the common day-to-day tasks that elderly people struggle with includes pinching.

Pinching is the action of griping something between the thumb and fingers without involving the palm. A few commonly known pinch techniques include the tip pinch, lateral pinch and three-jaw-chuck pinch (Ellis et al., 2004; Shih & Ou, 2005). It is important to understand the different pinching mechanisms and techniques. Although people usually pinch with techniques based on their experience and familiarity, the pinch force exertion is not comparable across different techniques (Ng, Bee, Saptari, & Mohamad, 2014). A study by Heffernan and Freivalds (2000) found that the optimum pinch technique for die handlers was a combination of a small pinch span (1.27-3.81cm) and a 45° inward slant. There have been studies on different aspects of finger pinching, including a study on the relationship between grip force and grip stiffness (Höppner, McIntyre, & van der Smagt, 2013). When the grip kinematics and force transfer function from muscle to finger are changed, one can actively change the increase of grip stiffness with force with wrist flexion and thus change the grip stability. However, precautions should be taken as all deviating wrist positions were found to degrade pinch strength (Imrhan, 1991). Among all components, finger strength is one of the major components often measured among elderly patients with stroke (Canning, Ada, Adams, & O'Dwyer, 2004; Harris & J Eng, 2007; Heller et al., 1987).

Several studies have looked into the variations in handgrip force and endurance among elderly people (Desrosiers, Bravo, & Hébert, 1997; Massy-Westropp, Gill, Taylor, Bohannon, & Hill, 2011; Nilsen et al., 2011; Nurul Shahida, Siti Zawiah, & Case, 2015; Wallström & Nordenskiöld, 2001) in addition to some studies on hand pinch strength among the elderly (Bae et al., 2015; Shin et al., 2012; Wei Lam et al., 2015; Wu, Chiu, & Hou, 2015). Researchers have also looked into the effects of aging on touch (Wickremaratchi & Llewelyn, 2006), and a possibility in the reduction of grip capacity in cases of reduced tactile sensibility such as numbness, glove use, or sensory deficit (Enders & Jin Seo, 2011). However, there appear to be few studies that examine how reduced and increased tactile sensibility affect the pinch force and pinch endurance of elderly people. In addition, many of the aforementioned studies are statistical in nature, and mostly provide fundamental inferences of pinch grip effects as precursor steps to enhance the body of knowledge and understanding of pinch grips. Few studies attempt to cover the problem-solving and innovation processes that extend from investigative outcomes of the aforementioned fundamental research. Hence, this study aims to not only uncover the effects of tactile sensibility on the pinch force and endurance among elderly people, but also look into how the theory of inventive problem solving (TRIZ) can be used to potentially resolve the issues that arise from the outcomes of the statistical inferences.

Pinch force and endurance time are selected as output variables for this study. Endurance time is measured using a stopwatch, while pinch force is measured using flexiforce pressure sensors. The data is analysed using the two-sample variance test and two-sample T-Test, and the TRIZ tools and techniques involved in this study include engineering contradiction, physical contradiction, substance field modelling, 40 inventive principles and 76 standard inventive solutions.

Literature Review

The change in aging muscle can come in two forms, namely normal (sarcopenia) and abnormal (example, cancer-related anorexia). Sarcopenia is the age-related decrease of lean muscle mass (Evans, 2010; Siparsky, Kirkendall, & Garrett, 2014). This phenomenon changes a person's activeness and reduces his/her quality of life. There are three stages of sarcopenia in old people as defined by the European Working Group on Sarcopenia in Older People (EWGSOP) in 2010 (Mitchell et al., 2012). Pre-sarcopenia is only the loss of muscle mass. Sarcopenia includes muscle loss that occurs together with reduced strength or physical performance, while severe sarcopenia entails muscle loss together with loss of strength and physical performance.

Muscle mass directly corresponds to age and changes accordingly as shown in Fig 1. Generally, people would experience increased muscle mass in their youth, maintained muscle mass during midlife and decreased muscle mass in later years (Dodds et al., 2014). Quantifiably speaking, after the age of 50 years, people would begin to lose an approximated 1 - 2 % of their muscle mass each year (Keller & Engelhardt, 2014; Marcell, 2003). Consequently, the probability of sarcopenia increases.

Sarcopenia is also significantly affected by the metabolic changes of aging (Evans, 2010). These changes come in the form of increased insulin resistance and higher body fat percentage, resulting in an elderly person's decrease in muscle turnover and repair abilities. Besides chronic inflammation, factors such as lower physical activeness, hormone excretion and nutrition contribute to the complex changes in the aging body, which play a role in the decrease of the body's muscle mass (Bainbridge et al., 2011).

The human skeletal muscle has been described with the term "plasticity" because of the malleability of muscle fibres (Pette, 2007). Plasticity is a common term in neurophysiology, while in the context of muscle physiology, the terminally differentiated muscle fibre is known as a versatile entity rather than a fixed unit. This feature of the muscle is advantageous for the elderlies as with training, it can adapt to demands throughout the human life span. In other studies, Heath and Hagberg (1981) and Seals and Hagberg (1984) found that with training, adults of ages between 60 and 80 can experience a 20 - 30 % increase in aerobic fitness. Central cardiovascular strengthening and peripheral muscle adaptation are causes for the aerobic fitness improvements. Therefore, it is vital that elderlies continue to remain active to continually drive muscles. The importance of keeping the fingers active with different types of movements is further emphasised in a study on midlife female dentist whereby dentist with low variation in work task history are at a higher risk of low pinch grip strength (Ding, Leino-Arjas, Murtomaa, Takala, & Solovieva, 2013).

Type I and type II fibres are age-related changes in muscle fibre distribution. Type I fibres are highly resistant to fatigue and capable of metabolising fat for energy expenditure while type II fibres contract faster and produce a large tension output but fatigue quickly. Physically, type I fibres are small, slow contracting, low-tension output fibres and type II are larger fibres. Although the exact numbers are unknown, it was found that aging leads to an increased percentage of type I fibres compared to type II (Larsson & Karlsson, 1978). The lesser number of type II fibres could possibly be the reason for muscle strength decrease as people age (Frontera, Meredith, O'Reilly, Knuttgen, & Evans, 1988).

According to researchers, the increase of type I fibres could be due to motor nerves having trophic influence on muscle fibres (Bárány & Close, 1971). The most probable explanation to this occurrence would be the reorganisation of aging motor units. Initially when the number of active motor units decrease, the remaining motor unit pool increases in size (Brown, 1972). This increase in size of active motor units is possibly due to new collaterals from motoneurons in the type I pool branching out to non-functioning fibres. Higher tension type II fibres will contribute less to tension output as low tension type I fibres would be predominant. In summary, elderlies would have smaller and weaker muscle mass due to the loss of type II fibres (Kirkendall & Garrett, 1998).

Tactile sensory feedback is an essential element of life (Badawy & Alfred, 2019). Elderly people often have diminished tactile sensibility and decreased hand dexterity. This could lead to the act of over-gripping objects during activities of daily living and cause hand-related injuries. The preceding predicament begs the need for researchers to conduct more studies on anthropometry and ergonomic risk factors in order to design special devices for elderly people (Syed Naqvi, 1993). In a certain study, elderly and young adults were requested to use a pulp pinch (a pinch technique that uses the thumb and index finger) to grip a small object with varying slipperiness. The study concluded that old people on average employ twice as much force as young people when they pinch. This excessive force is a response to poor tactile sensibility (Cole, 1991). For this study, the pulp pinch was selected as the type of pinch technique to be experimented on according to support from previous studies (Cole, 1991; K Li, N Wei, & S Yue, 2016; Ke Li, Na Wei, & Shouwei Yue, 2016). It was also suggested that the pulp pinch was one of the more commonly used dual finger pinching technique with regard to maximum strength applications for small objects (B Swanson, B Matev, & de Groot, 1970).

Besides friction, tactile sensibility allows individuals to detect other physical signals such as force, temperature, vibration and electricity (Tomimoto, 2011). The fingerprints also function to restrict slipping and support optimum friction. The friction coefficient can change depending on environment conditions such as the humidity of the surroundings and sliding surface (Hyun-Yong, Shimada, & Kawamura, 1996).

Results

3.1 Two-sample variance test for pinch force

For this study, the hypotheses proposed for the two-sample variance test are as such:

H_{01a}: There is no significant difference in the elderly individual's pinch force variance under the conditions of reduced and increased tactile sensibilities.

H_{1a}: There is a significant difference in the elderly individual's pinch force variance under the conditions of reduced and increased tactile sensibilities.

H_{01a}refers to the null hypothesis, while H_{1a}refers to the alternative hypothesis. The results of the two-sample variance tests for the elderly individual's pinch force with differing sensibilities are shown in Table 1. The results show that for both test methods (F-Test and Levene's Test), there is no significant difference in the elderly individual's pinch force variance with reduced and increased tactile sensibility ($p > 0.05$). Therefore, H_{01a} is supported and H_{1a} is rejected, and the variance is assumed to be equal. Further analysis on this would require the assumption of equal variance to be considered.

3.2 Two-sample T-test for the mean pinch force

In Minitab version 16, checking the "assume equal variances" checkbox was needed when conducting the two-sample T-Test. The hypotheses proposed for the two-sample T-Test are as such:

H_{01b}: There is no significant difference in the elderly individual's mean pinch force under the conditions of reduced and increased tactile sensibilities.

H_{1b}: There is a significant difference in the elderly individual's mean pinch force under the conditions of reduced and increased tactile sensibilities.

H_{01b}refers to the null hypothesis, while H_{1b}refers to the alternative hypothesis. The results of the two-sample T-Test for the elderly individual's mean pinch force under the conditions of reduced and increased tactile sensibilities are shown in Table 2. The results suggest that there is enough evidence for a significant difference to exist in the elderly individual's mean pinch force generated under the conditions of reduced and increased tactile sensibilities. Hence, H_{01b} is rejected, and H_{1b} is supported.

Upon further investigation, it is found that the mean pinch force generated from reduced tactile sensibility is higher compared to the one generated from increased tactile sensibility (Pinch force for reduced tactile sensibility = 242.6 N, Pinch force for increased tactile sensibility = 211.6 N). This finding suggests that the overall pinching force of the elderly population is higher with lower tactile sensibility as compared to that of with higher tactile sensibility.

3.3 Two-sample variance test for endurance time

A two-sample variance test is performed in order to see if a significant difference existed in the endurance time variance for elderly individuals under the conditions of reduced and increased tactile sensibility. For this study, the hypotheses proposed for the two-sample variance test is as such:

H_{02a}: There is no significant difference in the elderly individual's endurance time variance under the conditions of reduced and increased tactile sensibilities.

H_{2a}: There is a significant difference in the elderly individual's endurance time variance under the conditions of reduced and increased tactile sensibilities.

H_{02a}refers to the null hypothesis, while H_{2a}refers to the alternative hypothesis. The results of the two-sample variance tests for this section are shown in Table 3. For Levene's Test, it was found that there is no significant difference in the elderly individual's endurance time variance under the conditions of reduced and increased tactile sensibility ($p > 0.05$). However, the F-Test method revealed that a significant difference existed in the elderly individual's endurance time variance under the conditions of reduced and increased tactile sensibility ($p < 0.05$). Since one of the test methods suggested that there is a possible violation in the homogeneity of the variance, it would be safer to assume that the variance in this case is unequal. With this assumption, the F-Test results are accepted. Therefore, H_{02a} is rejected and H_{2a} is supported. Further analysis on this would require the assumption of unequal variance to be considered.

3.4 Two-sample T-test for the mean endurance time

The violation in the assumption of homogeneity of variance can be overcome by not using the pooled estimate for the error term for the t-statistic, instead, by using an adjustment to the degrees of freedom using the Welch-Satterthwaite method. In order to perform this analysis in Minitab version 16, the researchers would just need to uncheck the "assume equal variances" checkbox when conducting the two-sample T-Test. The hypotheses proposed for the two-sample T-Test is as such:

H_{02b}: There is no significant difference in the elderly individual's mean endurance time under the conditions of reduced and increased tactile sensibilities.

H_{2b}: There is a significant difference in the elderly individual's mean endurance time under the conditions of reduced and increased tactile sensibilities.

H_{02b}refers to the null hypothesis, while H_{2b}refers to the alternative hypothesis. The results of the two-sample T-Test for the elderly individual's mean endurance time are shown in Table 4. The results suggest that there is enough evidence for a significant difference to exist in the elderly individual's mean endurance time under the conditions of reduced and increased tactile sensibilities. Hence, H_{02b} is rejected, and H_{2b} is supported.

Additional observations revealed that the mean endurance time to which the elderly people used to sustain their pinch under the condition of reduced tactile sensibility was higher compared to the one under the condition of increased tactile sensibility (Endurance time for reduced tactile sensibility = 2.425 s, Endurance time for increased tactile sensibility = 1.808 s). This finding suggests that the pinching endurance of the elderly population under reduced tactile sensibility conditions is higher as compared to that of increased tactile sensibility conditions. Endurance in this study is the ability to sustain the pulp pinch for as long as possible. This is also a measure of muscle fatigue. Muscle fatigue was found to affect the coordination angle and force control of fingers (Hu, Wei, Li, & Li, 2018). All these factors, including tactile feedback influences the endurance abilities of elderlies.

3.5 Engineering contradiction

A TRIZ engineering contradiction is an improvement in one characteristic of a system which results in the degradation of another characteristic. An engineering contradiction is a situation in which an attempt to improve one parameter of a system leads to the worsening of another parameter. An engineering contradiction has the following structure:

If … (manipulative variable changes)

Then … (responding variable #1 improves)

But … (responding variable #2 worsens)

Using the TRIZ method, an engineering contradiction from the experimental results can be constructed as such:

If the elderly person pinched with reduced tactile sensibility,

Then they would tend to hold their pinch tightly for a longer duration,

But they tend to overexert their pinch grip.

After establishing the engineering contradiction, proposed recommendations can be filtered out through the identification of the appropriate TRIZ inventive principles. The TRIZ inventive principles are simple ways to resolve engineering contradictions. There are 40 TRIZ inventive principles altogether. The inventive principles can be extracted from the contradiction matrix by first identifying the appropriate TRIZ system parameters linked to the engineering contradictions. There is a total of 39 TRIZ system parameters.

Table 5 and Table **6** present the system parameters and inventive principles for the engineering contradiction. The possible outcome of this study could be to potentially design an ergonomic device that assists its user in performing a longer and more sustainable pinch grip duration without overexerting the fingers. With this in mind, the inventive principle of partial action was selected.

3.6 Physical contradiction

A physical contradiction involves two opposite requirements on a single object (Ko, Lu, & Lee, 2016). These requirements cause conflict in the functionality of that particular object. It is also an engineering system that requires conflicting properties from the same parameter. The steps to resolve a physical contradiction are listed as such:

1. Construct two opposite requirements for one parameter of a system.
2. Determine the correct strategy to resolve the contradiction.
3. Identify the most suitable inventive principles which will lead to ideas that solve the problem.

For this study, the physical contradiction can be formulated as such:

*Elderlies need to pinch with reduced tactile sensibility in order to hold their pinch tightly for a longer duration, **AND** elderlies need to pinch with increased tactile sensibility in order to not overexert their pinch grip.*

The strategy used here to resolve the physical contradiction is known as separation in space. This is because there is an operating space to pinch tightly and an operating space to avoid overexertion. These parameters are to be fulfilled at the same time but can be at different spaces. Based on the 40 inventive principles, the inventive principles used for the separation in space strategy include:

#1 Segmentation

#2 Taking out

#3 Local quality

#17 Another dimension

#13 The other way around

#14 Curvature

#7 Nested doll

#30 Flexible shells/Thin films

#4 Asymmetry

#24 Intermediary

#26 Copying

The segmentation and the-other-way-around principles were selected for further deliberation on possible recommended solutions in resolving the physical contradiction.

3.7 Substance-field analysis

The substance-field (Su-Field) analysis is another TRIZ problem solving tool. It is used to analyse and improve the efficacy of technical systems. The most important phase of the Su-Field analysis is the last step which is to manually implement the solution to a system (Yan, Zanni-Merk, Rousselot, Cavallucci, & Collet, 2013). The Su-Field mainly consist of a few main fields which are Mechanical, Acoustic, Thermal, Chemical, Electric and Magnetic (MATCHEM). A field makes up the most basic model of an interaction. Any interaction can be formulated as the interaction between two substances. The statistical findings and TRIZ contradictions of this study suggested that elderlies with poor tactile sensibility in their fingers tend to pinch more forcefully, causing stress to their fingers. Using the Su-Field analysis, the interactions between the fingers and pinched object can be modelled. The type of model identified would determine the class of standard inventive solutions (from the 76 TRIZ Standard Inventive Solutions) to be used for the particular modelled problem.

Fig 2 presents the Su-Field model of this study. S1 refers to the first substance which represents fingers. S2 represents the pinched object. F1 is the mechanical field which includes the interaction between fingers and objects. This model is known as a harmful Su-Field model, which is normally represented by a curly arrow from S1 to S2. The model implies that the fingers are harmfully pinching the object. From the list of 76 Standard Inventive Solutions, class 1.2 is used as a reference to resolve the problem. This class includes various methods of eliminating or neutralising harmful effects. Sub-classes 1.2.1 and 1.2.4 were finally chosen as the solution models.

Discussion

4.1 Engineering Contradiction - Partial action

Although grip force may be highly suboptimal, it can benefit the elderlies (Shim, Lay, Zatsiorsky, & Latash, 2004). A higher grip force would prevent objects from leaving the hand even if load force changes. These forces could be accelerations in a vertical direction or changes in the grip force. Among less steady elderlies, occurrences like these can be expected (Burnett, Laidlaw, & Enoka, 2000; Enoka et al., 2003). Elderlies were found to produce grip forces that were on average twice as large as those produced by younger ones during a precision pinch grip experiment (Cole, 1991). This excess grip force represents a strategic response to tactile sensibility impairment which also contributes to impaired dexterity.

Excess force will produce a stronger pinch grip yet places more stress on finger muscles, that can cause long term injuries. Partial action is an appropriate strategy to assist elderlies in ensuring that they do not overexert their fingers in a pinching application. This strategy can be executed by pinching using less of the originally desired force when the exact intended force is difficult to achieve, rather than exerting a high pinch force in a single attempt. In fact, research found that elderlies often utilise a probing pinching approach which causes a larger force fluctuation (Enoka et al., 2003). This is a natural response to the inability of elderlies to ramp up finger force. Increasing friction would naturally cause people to grip more securely, which then allows for better pinch force control. Another more unconventional method would be to explore the use of dampers which can absorb the extra force without compensating strength and firmness of the pinch.

4.2 Physical Contradiction

4.2.1 Segmentation

Besides finger strength, finger individuation is an important component of hand function. Finger individuation is the ability to discreetly manipulate fingers. Studies have shown that stroke patients were unable to produce independent finger force and unable to synchronise their multi-finger force (Kim, Kim, & Yoon, 2014). Independent finger movements were found to be restricted as motor cortex or corticospinal tract worsens (Lang & Schieber, 2003; Schieber, Lang, Reilly, McNulty, & Sirigu, 2009). According to the aforesaid research, this was particularly obvious for the middle, ring and little finger as they were found to be substantially impaired. While finger individuation was found to be severely impaired among stroke patients, the general elderlies are not spared from this predicament. Researchers found that the deep long flexors of fingers were unable to selectively contract, hence limiting independency (Kilbreath & Gandevia, 1994). In a study among healthy adults, mechanical coupling was a major cause of finger independency reduction especially in the index, middle and ring fingers (Lang & Schieber, 2004).

When gripping small objects, one must have the individuation ability to position fingers in the correct orientation and exert enough force to grip the object (Wolbrecht et al., 2018). This understanding of how each finger changes differently with respect to age should change the method of designing a finger pinching assistant tool. Instead of studying pinching as a single finger’s action, segmentation suggests that breaking the action down to smaller components of individual fingers would be more appropriate as supported by past research (Kilbreath & Gandevia, 1994; Lang & Schieber, 2004). With the use of this principle in the design of a pinching enhancing tool, more emphasis should be given to weaker fingers like the middle, ring and little fingers in order to compensate for the severe impaired individuation experienced.

4.2.2 The other way around

The elderlies were found to produce a higher antagonistic moment which acts against the direction of total moment (Shim et al., 2004). Similar to the produced excess forces, this can be viewed as an inefficient griping method, though it increases stability. Antagonist moments increase the apparent stiffness of the hand and can be a passive resistance to variations in torque. In other studies, researchers found that the central nervous system was unable to organise finger synergies such that finger forces tend to cancel each other out (Latash, Scholz, Danion, & Schöner, 2001, 2002). Researchers concluded that the central nervous system requires some time to organise the stabilisation in the finger force of negative covariation (Shim, Latash, & Zatsiorsky, 2003). During prehensile tasks, fingers pre-produce a nonzero force which acts against external torque (Shim et al., 2004). These finger phenomena occur instinctively to increase the safety margins of elderlies as they use their fingers.

Using the principle of the other way around, it could be beneficial to view antagonist moments from another perspective. Instead of trying to eliminate these natural age-related responses of the fingers, factoring this into future studies or medical devices would enable people to age gracefully as their bodies intend.

A device utilising the principle of the other way around in this case would pay attention to the preloading force of the elderly's fingers. Instead of designing something that restricts initial force application entirely, the device should allow fingers to apply preloading force first before assisting it with mechanisms. This would also allow older individuals to remain active as a countermeasure for expected loss of strength and endurance. Elderlies often experience decreased walking speed, sit-to-stand transition time, frequent falls and worsening balance as physical strength decreases. However, a study among elderlies of 90 years of age with resistance training showed an improved strength of up to 175 % and improvements in functional mobility (Fiatarone et al., 1990). It is never too late to start being active as researchers found that for many patients, age-related effects on skeletal muscles are still reversible (Fiatarone & Evans, 1993).

4.3 Substance-field analysis

4.3.1 Sub-class 1.2.1: Removal of harmful effect by introducing S3

Fig 3 shows a chain Su-Field model, which is a modified version of the previous harmful Su-Field by adding another field (F2) and substance (S3). S3 is added to separate substances S1 and S2. It should be a substance that can potentially reduce the harm on the fingers while pinching. In this scenario, S3 can include adding friction between the fingers and pinched object. This proposition, which can take the form of rubber pads or gloves, improves tactile sensibility, leading to a plausible increase in force accuracy and reduced overexertion. F2 in the diagram remains as a mechanical field.

For the elderlies, the mechanical action of pinching causes a harmful effect. As people age, the tactile sensibility of hands becomes impaired (Cole, 1991; Ranganathan, Siemionow, Sahgal, & Yue, 2001; Rantanen et al., 1999). Because of this, elderlies are unable to pinch with the accurate amount of force and often overexert their fingers to secure a stable grip. This harms the fingers and causes long-term injuries. Adding a new substance between the finger and object could potentially eliminate this effect.

Rubber gloves are popular tools used for increasing friction between the fingers for any hand-holding application. In various industries such as sports, culinary arts and manufacturing, rubber gloves can significantly improve the pinching ability by increasing contact friction. Elderlies could also benefit from pinching with extra friction. This can be incorporated into devices for activities of daily living. One example includes the NuMuv Grip-Aid as shown in Fig 4. The NuMuv Grip-Aid is a device that aids people with grasping issues by providing a larger grasp surface for the user to work with (Obmaces, 2015). This soft, egg shaped holder works easily with toothbrushes, eating utensils, pencils and other objects. A study in 2015 discovered a progressive increase of grip-to-load force during the precision pinch of low-mass objects (less than 30 g) (Hiramatsu, Kimura, Kadota, Ito, & Kinoshita, 2015). The same study discussed the possibility of how a decreased level of tactile feedback plays a role in inefficient low-mass grip force control. With reference to the analogy of this invention, a similar tool can be introduced for elderly people to increase finger friction and reduce the harmful effects caused by slippery pinching.

4.3.2 Sub-class 1.2.4: Counteracting the harmful effect of F1 by neutralising it with F2

Fig 5 is a double Su-Field model, which is a modified version of the original harmful Su-Field by adding another field (F2) to neutralise the harmful effects of F1. The mechanical field from F1 produced by the fingers pinching the object generates harmful effects. These effects can be negated by adding F2. Some of the possible fields could include the optic or acoustic field. This solution model does not separate S1 and S2 and ensures that the fingers remain in contact with the pinched object. As people age, eyesight begins to deteriorate. Poor eyesight has a strong correlation with poor finger pinching (Lin et al., 2019; Ribeiro & Oliveira, 2007; Shumway-Cook & Woollacott, 2007). The inability to clearly gauge objects would cause the inability to properly apply the appropriate force. The incorporation of LED sensors on a device that aids pinching would be able to provide a clear signal to indicate the user once sufficient force is detected for the pinching action.

It is important to consider other forms of mediums in which information regarding finger gripping can be easily processed by elderlies. Auditory feedback is one of the possible substitutes to visual sensors (Levy-Tzedek, Hanassy, Abboud, Maidenbaum, & Amedi, 2012; Portnoy, Halaby, Dekel-Chen, & Dierick, 2015). With sufficient practice, auditory feedback could assist day-to-day activities and prevent household accidents. Auditory feedback, like an alarm or buzzer, could be a suitable component to assist in providing feedback regarding pinch force to elderlies. A pincer chopstick developed by Chang, Huang, Chen, and Wang (2007) is an example of a substituting device for people with impaired hands. Without any prior experience, users with this pincer chopstick on their non-dominant hand performed better as compared to when using traditional chopsticks. This will ensure elderlies pinch with the adequate amount of force to prevent injuries. Besides that, it also ensures that elderly individuals avoid sustaining the high pinch force for an extended duration in order to avoid unnecessary holding postures which can cause muscle fatigue and cumulative trauma disorders such as carpal tunnel syndrome (Syed Naqvi, 1996).

Conclusion

With aging being the main cause of sarcopenia, elderly people are at high risk of facing degradation in hand functions, and this could severely affect their quality of life. The silver lining for elderlies would be that with proper exercise, muscles can get stronger and functional enough for them to prevent or prolong the degenerative loss of skeletal muscle mass. However, a major gap still exists in the development of assistive tools that can support the hand functions of elderly people who are already suffering from sarcopenia or any other frailty syndrome.

This study confirms that elderlies with poor tactile sensibility in their fingers commonly pinch objects with excessive force and extended durations. Such acts could harm their fingers if not assisted with the right tools or devices. Hence, a device that can intelligently assist elderlies in pinching objects with predictive and accurate stress detection abilities could be developed and incorporated into various products and designs. Some of the ideas of this study such as the inclusion of audio sensors and utilisation of preloading in finger strength can be considered as recommendations from different perspectives with a similar aim, which is to resolve the problem of poor pinch performance due to the lack of tactile sensibility in fingers.

In spite of the findings of this study, more experiments and tests are required to filter and finally design a tool with real value to elderlies with regard to pinching activities. Nonetheless, this study still provides researchers with preliminary and mechanistic insights on design directions, ideas and concepts that can be undertaken to resolve pinch grip issues among the elderly. The success of producing such designs could disentangle the problems in accommodating the use of fragile fingers and deteriorating muscles among elderly people and provide more avenues in resolving more pinch grip-related issues.

Methods

This study was designed to investigate the effects of tactile sensibility on pinch force and pinch endurance. With the statistical information, further analysis using the TRIZ methodology can be conducted. This systematic approach would allow for the formulation of TRIZ engineering contradictions, physical contradictions and substance field models, and the generation of TRIZ principles which support the conceptualisation process. The targeted test subjects for the experiment were elderlies above the age of 55. Participants above the age of 55 years old, who were physically healthy with no heart failure, neurological diseases, joint injuries, muscle diseases or injuries of the fingers, hands and arms were eligible to participate in this study.

A total of 32 subjects aged 55-65 years old were randomly selected for the experiment which was conducted in a span of 20 days (from 8 October to 27 October 2019). Although the activeness of these individuals did not become a variable in the experiment, an equal amount of elderlies with frequent and infrequent hand usages were selected to ensure that the results were unbiased. The same balance in gender was also ensured during the participant selection. In order to replicate pinching action, an experimental apparatus was fabricated as shown in Fig 6 (A). Subjects were required to wear gloves with sensors attached to their fingertips as shown in Fig 6 (D). Fig 6 (B) shows a participant pinching a binder clip mounted on the experimental apparatus using the experimental gloves.

The experiment was conducted to collect data on pinch force and endurance time. In order to obtain results for pinch force, subjects were required to pinch the apparatus at their maximum limit. The maximum pinch force was recorded using the I-Scan software. For endurance time, subjects were asked to sustain their pinching activity for as long as possible (Li, Evans, Seitz, & Li, 2015; Li, Marquardt, & Li, 2013). From Fig 6 (C), endurance time was recorded using a stopwatch. Tactile sensibility in this experiment was controlled by using different types of gloves. Cotton gloves were used for reduced tactile sensibility while rubber gloves were used for increased tactile sensibility. It is important to note that the authors had no access to information that could possibly identify the individual participants during or after the data collection.

For both sets of data (pinch force and pinch endurance time), a two-sample variance test and T-Test were performed. The two-sample variance test was performed to test if a significant difference in the variance existed. The common reason to compare variance is a check for homogeneity of variance before further tests like ANOVA or T-Tests are performed (Hosken, Buss, & Hodgson, 2018). Using Minitab version 16, the assumption of homogeneity of variance was done with Levene's Test and F-Test. The Levene's Test applies to any continuous distribution while the F-Test is based on the normal distribution. If equal variances are assumed (null hypothesis supported, and alternative hypothesis rejected), there is a better possibility of minimising the Type I error, which is the rejection of a true null hypothesis (known as a "false positive" finding).

With the assumption of homogeneity in variance, the pooled estimate for the error term for the t-statistic can be used. The T-Test was used as it is more accurate than a corresponding normal test and is just as powerful (Liu & Sun, 2019). The T-Test can determine if a significant difference between the means of two groups existed. Assuming the dependent variable fits a normal distribution, the probability of a particular outcome becomes identifiable. The statistical T-Test results would assist the researchers in identifying contradictions related to the problem in order to continue with the problem-solving approach using TRIZ methodology.

TRIZ is a Russian Acronym which stands for the Theory of Inventive Problem Solving. It is an algorithmic problem-solving technique which uses logic rather than intuition to stimulate the aptitude in solving problems innovatively (Yeoh, Yeoh, & Song, 2015). According to Yeah (Yeoh, 2014), TRIZ follows a systematic process that is highly reliable, predictable and repeatable. Furthermore, TRIZ is applicable across all fields of study and can address all sorts of problems related to technology, engineering, business, social science, arts, culture and philosophy (Souchkov, Hoeboer, & Zutphen, 2007). Fig 7 shows the TRIZ process used in this study.

Declarations

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Authors’ contributions

DWHT developed the methodology including the use of TRIZ for problem-solving. PKN conceptualised the research goals and methods to achieve them. PKN also managed the data analysis. EEMN assisted in the research background and identification of research gaps. All authors have read and approved the final manuscript.

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Availability of data and materials

The experimental data has been deposited in the Figshare data repository, which can be found at: https://doi.org/10.6084/m9.figshare.9805274.v1

Ethics approval and consent to participate

All participants gave their written informed consent prior to the experiments, in which all procedures and protocols were approved by the Research Ethics Committee (REC) from the Collaboration and Innovation Centre (CIC) of the R&I Division, Multimedia University Malaysia. The research ethics approval for the project was granted with the approval number EA0032019, and the approval letter was endorsed by the CIC Director cum REC Secretariat of the university.

Consent for publication

Not Applicable

Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1. Two-Sample Variance Tests for the Elderly Individual's Pinch Force Variance under the Conditions of Reduced and Increased Tactile Sensibilities

Method	DF1	DF2	Statistic	p [a]
F-Test (normal)	323	323	1.17	0.169
Levene's Test (any continuous)	1	646	1.35	0.246

DF - degree of freedom

[a] probability values calculated using the Variance Test

Table 2. Two-Sample T-Test for Elderly Individual's Mean Pinch Force under the Conditions of Reduced and Increased Tactile Sensibilities

Samples	N	Mean	Std Dev	SE Mean	p [b]
Pinch Force (Reduced Tactile Sensibility)	324	242.6	89.2	5.0	0.000
Pinch Force (Increased Tactile Sensibility)	324	211.6	82.6	4.6	
T-Test of Difference	0 (versus not equal to 0)				
T-Value	4.59				
Both use Pooled StDev	85.9276				

N - population size; Std Dev - standard deviation; SE Mean - standard error mean

[b] probability values calculated using T-Test

Table 3. Two-Sample Variance Tests for the Elderly Individual's Pinch Endurance Time Variance under the Conditions of Reduced and Increased Tactile Sensibilities

Method	DF1	DF2	Statistic	p [a]
F-Test (normal)	323	323	1.33	0.011
Levene's Test (any continuous)	1	646	1.65	0.200

DF - degree of freedom

[a] probability values calculated using the Variance Test

Table 4. Two-Sample T-Test for the Elderly Individual's Mean Endurance Time under the Conditions of Reduced and Increased Tactile Sensibilities

Samples	N	Mean	Std Dev	SE Mean	p [b]
Endurance Time (Reduced Tactile Sensibility)	324	2.425	0.800	0.044	0.000
Endurance Time (Increased Tactile Sensibility)	324	1.808	0.694	0.039	
T-Test of Difference	0 (versus not equal to 0)				
T-Value	10.48				

N - population size; Std Dev - standard deviation; SE Mean - standard error mean

[b] probability values calculated using T-Test was selected.

Table 5. System parameters for engineering contradiction

Engineering Contradiction Variables	System Parameters
Improving Variable	#11 Pressure/ Stress
	#15 Duration of Action of Moving Object
Worsening Variable	#10 Force

Table 6. Inventive principles from system parameters of engineering contradiction

Pairs of System Parameters	Inventive Principle
#11 & #10	#36 Phase transitions
	#35 Parameter changes
	#21 Rushing through/ Skipping
#15 & #10	#19 Periodic Action
	#2 Taking Out
	#16 Partial action

Figures

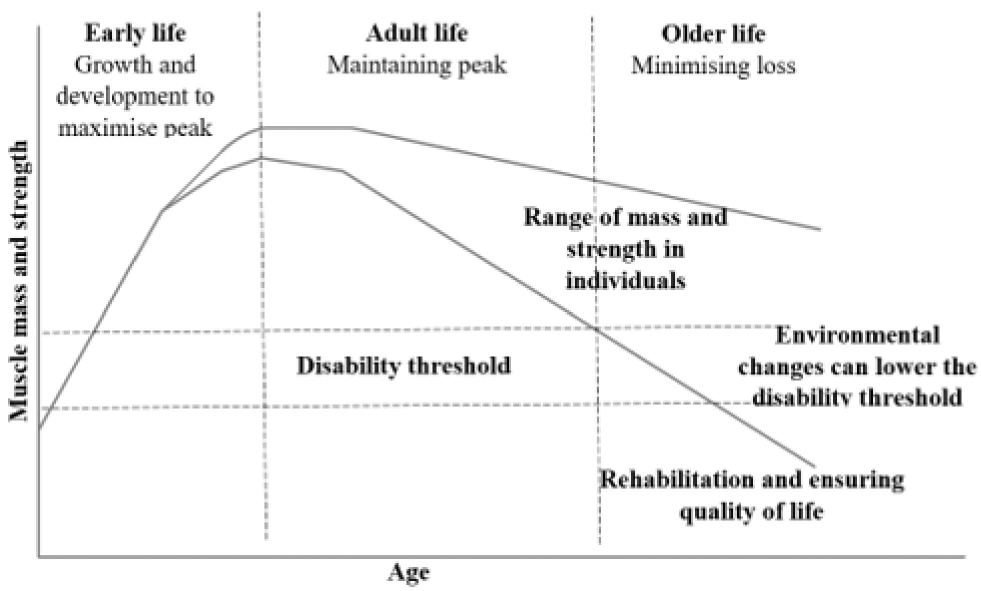

Figure 2

Changes in muscle mass and strength with respect to age (Sayer et al., 2008)

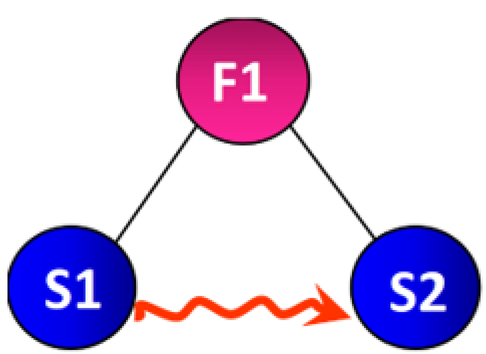

Figure 4

Harmful Su-Field of finger pinching

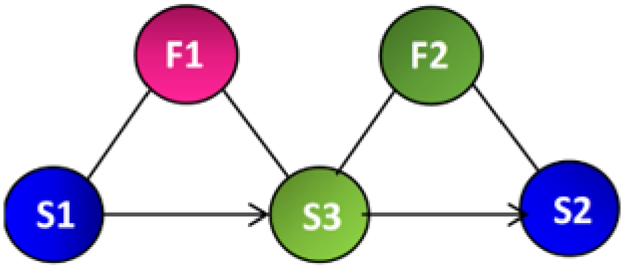

Figure 6

Adding another field and substance

Figure 8

NuMuv Grip-Aid, a device for hand mobility issues (Obmaces, 2015)

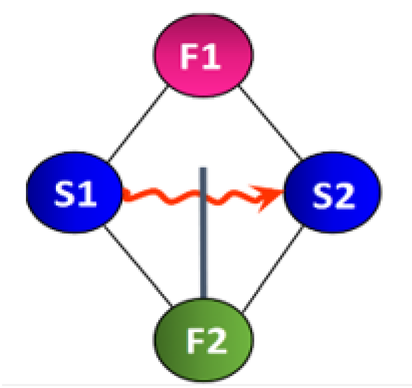

Figure 10

Adding another field to neutralise the harmful effects of F1

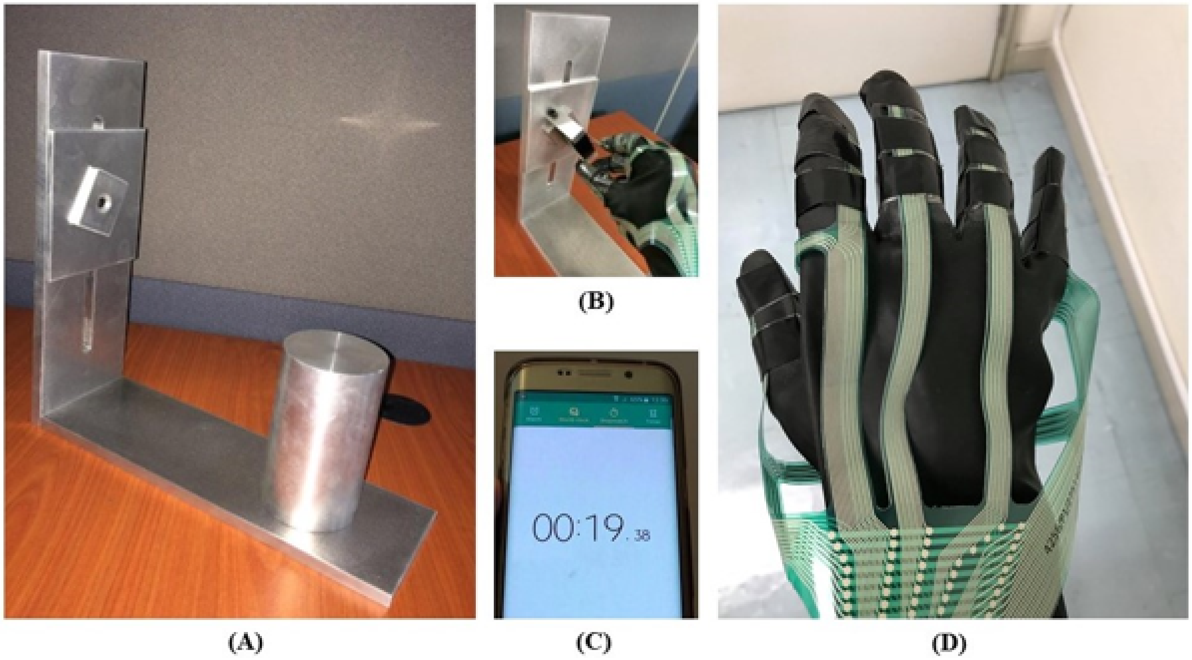

Figure 12

Apparatus used in strength and endurance pinch testing

Figure 14

TRIZ methodology used in this study