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A TRIZ-BASED APPROACH IN INVESTIGATINGFINGER GRIP FUNCTION DEGRADATION AMONG ELDERLIES

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ABSTRACT

This study aims to investigate the pressing issues of weak finger grip among elderlies and examine the underlying causes and potential solutions. The outcome of this study intends to benefit the development of ergonomic finger grip enhancers for the elderly. A problem-solving tool known as TRIZ was used to identify root causes to the problem and establish engineering contradictions which led to the solution models. The contradictions were resolved using proposed recommendations from some of the 40 inventive principles of TRIZ. The recommendations were cross-examined with existing inventions, concepts and ideas in order to substantiate their viability. The inventive principles generated from TRIZ included mechanics substitution/another sense, dynamisation and parameter changes. These individual principles led the researchers towards suggesting design ideas using visual feedback substitution, extended "finger" mechanisms to stabilise griping and devices to assist in force control. It may still be uncertain whether or not these ideas can integrate well with one another. However, as initial recommendations, these ideas have the potential to solve some of the root causes for poor finger grip due to the corresponding support found from previous studies.

Keywords: elderlies, finger grip, ergonomics, pinch, TRIZ.

1. INTRODUCTION

It is common to have experienced some form of minor injury to the fingers, hands or wrists that causes pain or swelling. These pain symptoms may not entirely be caused by the day-to-day activities but may have originated from the wear and tear or overuse in daily living activities. The problems in the fingers, hands or wrists could be caused by injuries or the effects of aging (Rosberg & Dahlin, 2018). Hand injury is usually a nagging, persistent hand weakness that is almost certainly not related to any serious medical problems. With that being the case, hand weakness can get worse if not resolved in a timely manner. Therefore, it is important to get medical advice if pain or discomfort is experienced in the fingers, hands or wrists.

The rapid growing population of elderly people is a serious issue in many countries. This unique demography profile becomes a challenge in helping elderlies stay healthy and active (Gul, Alam, Ibrar, Saleem, & Pervez, 2013; Kurnianingsih, Nugroho, Widyawan, & Lazuardi, 2015). As people age, the hand and finger functions start to deteriorate due to the degradation of body muscle, nerves and brain coordination. Cognitive deficits develop which affect the functions of the hands and fingers. The degeneration of critical players in the brain will affect the fine motor coordination of the elderly (Seidler *et al.*, 2009). In other words, when neurons can no longer effectively communicate successfully to other parts of the body that would be when an elderly person loses functions such as fine motor skills. In fact, a study in 2014 published that old age is directly related to poorer fine motor skills(Young Hoogendam *et al.*, 2014).

According to Mafauzy (2000), in the year 2020, Malaysians aged 60 years and above are estimated to reach 3.3 million. This figure is a 210% increase from the statistics in 1990 and makes up 9.8% of the total Malaysian population. The elderly also tends to be less healthy than the young population. Hence, the increase in the aged group is often associated with an increase in the prevalence of poor health. Physical changes of the body also restrict the day-to-day activities of the elderly. Weakness in hands, fingers, and wrists is often experienced by the elderly which could lead to losing their fine motor skills, having difficulties pinching objects and even degenerating into carpal tunnel syndrome.

If an elderly experiences stiffness, tingling, numbness, pain due to an inflamed finger joint, or the inability to straighten their fingers, the first response would be to obtain professional advice from a medical practitioner or physician. Finger exercises are often helpful to prevent finger weakness and to keep fingers active and strong (Chen, Lu, & Zhang, 2014). However, there appear to be limited studies that investigate the root causes of weak finger grips among elderly people along with the proposition of ergonomic solutions that potentially resolve these root causes. Therefore, this study aims to investigate the pressing issues of weak finger grip among elderlies, examine the underlying causes and propose potential ergonomic solutions to resolve the problem using the TRIZ methodology. The outcome of this research would then be extended to develop finger grip enhancers for the elderly to facilitate their day-to-day activities.

With the pressing aging Malaysian population, further efforts are needed to ensure that this group is not neglected. Although ageing is a natural process that is often accompanied by deteriorating body functions and sickness, more efforts can still be done to help the elderly maintain a good quality of life. Apart from medication and finger exercises, it is imperative for ergonomics researchers to investigate the root causes entailing the loss of finger grip strength among elderly people, and identify

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appropriate solutions in order to improve their independence and quality of life.

3. LITERATURE REVIEW

Muscle strength, total muscle cross-sectional area, muscle fiber number and motor unit number are some of the declines experienced with ageing (Booth, Weeden, & Tseng, 1994). Sarcopenia is the loss of skeletal muscle mass and strength due to the ageing body. Strength loss is primarily due to the decrease of muscle mass. Almost 30% of people above the age of 60 will have some sort of sarcopenia symptom (Doherty, 2003).

With the increase of age, hand abilities for activities of daily living also decrease. There is also a significant and positive correlation between the time required to complete various hand movement subtests and age (Hackel, Wolfe, Bang, & Canfield, 1992). Age was discovered to have an effect on variation force especially during submaximal force application (Galganski, Fuglevand, & Enoka, 1993). In a study relating to pinch force, the elderlies were found to have a handgrip force which was 30% lower than young people and also a 26% lower maximum pinch force. They were also less capable of maintaining a steady submaximal pinch force and precise pinch posture. Thus, according to this study, ageing has a deteriorating effect on overall hand finger abilities (Ranganathan, Siemionow, & Sahgal, 2001).

As human beings age, their pace of life starts to slow down, and this can be dangerous for the overall muscle health because immobilisation will lower the maximal firing rate of motor units while also decreasing twitch tension (Duchateau & Hainaut, 1990; Schultz, 1992). Besides a reduction in maximum muscle force among the elderly, researchers also discovered a decrease in the central motoneuron drive which limits the activities of daily living (Kamen, Sison, Du, & Patten, 1995). Elderly people have significantly lower maximal discharge rate, causing the inability to fully drive motor units, which suggests this to be a partial reason for the reduction of maximal force capacity among the elderly. These factors result in a decrease of maximal voluntary contraction force (Shim, Lay, Zatsiorsky, & Latash, 2004).

Adults were found to have reduced cortical neurons up to 35% by the age of 50(Eisen, Entezari, & Stewart, 1996; Henderson, Tomlinson, & Gibson, 1980). This will reduce both the sensory and motor functions of an individual. In an experiment, older subjects were found to have a lower number of motor units. This estimation was obtained through a multiple point stimulation test which collects samples of different stimulation along the median nerve (Doherty & Brown, 1993).

For old people, impairments in manipulation strength and dexterity are often attributed to neuromuscular changes such as a decrease in the number of motor neurons, an increase in motor neuron size, changes in motor unit discharge patterns, and changes in contractile properties (Galganski *et al.*, 1993). Using percutaneous electrical stimulation of single motor axons, older people were found to have larger surface-detected motor unit action potential sizes. With this, they also had notable motor unit twitch tensions and slower contraction time (Doherty & Brown, 1997).

Two of the most glaring decline of finger functions are the decline of hand strength (Boatright, Kiebzak, O'Neil, & Peindl, 1997; Giampaoli *et al.*, 1999; Rantanen *et al.*, 1999) and decrease of dexterity (Francis & Spirduso, 2000; Hackel *et al.*, 1992) in which extensive studies have been carried out in both areas. These factors result in poorer motor skills. Older people are weaker, have less force control, and have slower neuromuscular contractile properties. They also have a lower motor unit discharge rate and higher varying motor unit discharge at higher force levels (Roos, Rice, & Vandervoort, 1997).

Another reason for poor finger grip among the elderlies is due to poor eye sight. The elderly becomes increasingly reliant on visual feedback as grip strength gradually decreases. This is to compensate for declining muscle strength while performing daily activities. In an experiment to investigate how the presence or absence of visual feedback changes the stability of hand grip, older participants were found to have lower grip force output and lower grip stability control during non-visual feedback (Lin *et al.*, 2019). This study suggests that elderlies may have issues with performing everyday activities that require holding or griping objects due to their poorer eyesight. Because of age-related deterioration of physiological and functional performance, elderly adults may be unable to generate stable grip force outputs in the hands in order for them to manipulate objects while performing daily activities.

The decrease in vision would also affect the proprioception of an individual. With degrading proprioception, a person loses the ability to accurately detect body position movements which might lead to higher risk of falling, unusual joint biomechanics during functional activities and, if prolonged, degenerative joint diseases. Impaired proprioception comes with aging (Ribeiro & Oliveira, 2007). Most daily activities only require a submaximal grip force to control and move objects. These activities include holding a water bottle or turning a door knob. Therefore, it is more important for individuals to have submaximal stability in a grip force rather than a maximal grip force (Lin *et al*., 2019). Poor proprioception would affect a person's ability to control and apply the appropriate amount of pinch force.

Researchers found that participants had a higher grip score with visual feedback. Subjects aged between 18-24 years old were required to grip a dynamometer with and without visual feedback. Although the difference was small, it was still statistically significant beneficial for the establishment of clinical guidelines concerning grip strength (Weinstock-Zlotnick, Bear-Lehman, & Yu, 2011). For elderly people, when vision was not allowed during griping, grip force in the non-dominant hand was found to be significantly lower at 6.54% compared to when they were allowed to see the indicator (Lin *et al*., 2019). According toShumway-Cook and Woollacott (2007), when the eyes are open, it triggers our attention span and ocular motor system which provides more sensory input and increases neuromuscular control. Studies by

Vuillerme, Nougier, and Prieur (2001) suggest that with vision, subjects were able to adapt to the destabilising effect induced by muscular fatigue.

Older adults also had higher variation of force at lower force magnitude (Galganski *et al.*, 1993; Tracy, Maluf, Stephenson, Hunter, & Enoka, 2005). Tracy *et al.* (2005) found that greater force fluctuation among the elderly is likely contributed by difference in motor unit discharge as a significant relation was obtained. This substantiation is also echoed by Laidlaw, Bilodeau, and Enoka (2000) who found that older subjects had greater variability of discharge rates during isometric and anisometric contractions. The study also revealed that the elderly is less steady at lower target forces with lighter loads.

Bimanual coordination is where the brain must simultaneously control multiple movements, for example carrying out activities with both hands. Ageing will cause the degradation of the neuromuscular system which will affect daily activities that require bimanual coordination. In a study to investigate the effects of ageing on maximum grip force and the capacity to coordinate the control of both hands, elderly and young adults were tested by reciprocally gripping, holding and releasing a dynamometer with both hands at three different force levels. The elderly was found to have a lower maximum grip force in both hands and significantly longer alternating time control when switching between hands. The study concluded that ageing reduces the maximum grip force and bimanual coordination of two hands (Lin *et al.*, 2014).

Elderly people often have diminished tactile sensibility and decreased hand dexterity. This could lead to over-gripping during activities of daily living. In an experiment, elderly and young adults were required to use a pulp pinch (a pinch technique that involves using the thumb and index finger) to grip a small object with varying slipperiness. As predicted, the old subjects on average employed twice as much force as the young subjects. This excessive grip force is a response to poor tactile sensibility (Cole, 1991).

The most common solutions to this pressing issue would be for elderlies to have regular physical activities to preserve proprioception and strengthens muscles. Ribeiro and Oliveira (2007) found that regular physical activities can delay the decline of proprioception. Simple finger exercises over a long period of time could also reduce the inconsistency of the motor unit discharge rate, reduce fluctuations in the motor output of hand muscles and increase finger dexterity (Kornatz, Christou, & Enoka, 2005). Resistance exercises and pharmacological or nutritional interventions also play an important role (Doherty, 2003).

4. 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). This tool follows a systematic process that is highly reliable, predictable and repeatable (Yeoh, 2014).

The TRIZ methodology was selected for this study because it is known for solving difficult and complex problems that demand users to think outside the box (Ng, Jee, & Choong, 2016; Yeoh *et al*., 2015). Furthermore, TRIZ is applicable across all fields of study and can address all sorts of problems related to technology, business, social science, arts, culture, philosophy and so forth (Souchkov, Hoeboer, & Zutphen, 2007). The sequence of using the TRIZ methodology for this research is proposed in Figure-1.

A Cause-and-Effect-Chain (CEC) analysis diagram is a structured way of expressing the hypothesis about the cause of a problem or about why something is not happening as desired. This method helps to focus the researcher's attention on the process where a problem is occurring and to allow for the constructive use of facts to narrow down on the actual causes. The problem statement for this study can be identified as "Elderlies having degrading finger function". With this to work from, the question "why" was asked until the investigator reaches the cause that is a fundamental law of physics or chemistry, or technology limit. The end of the chain is a potential actual root cause to the main problem.

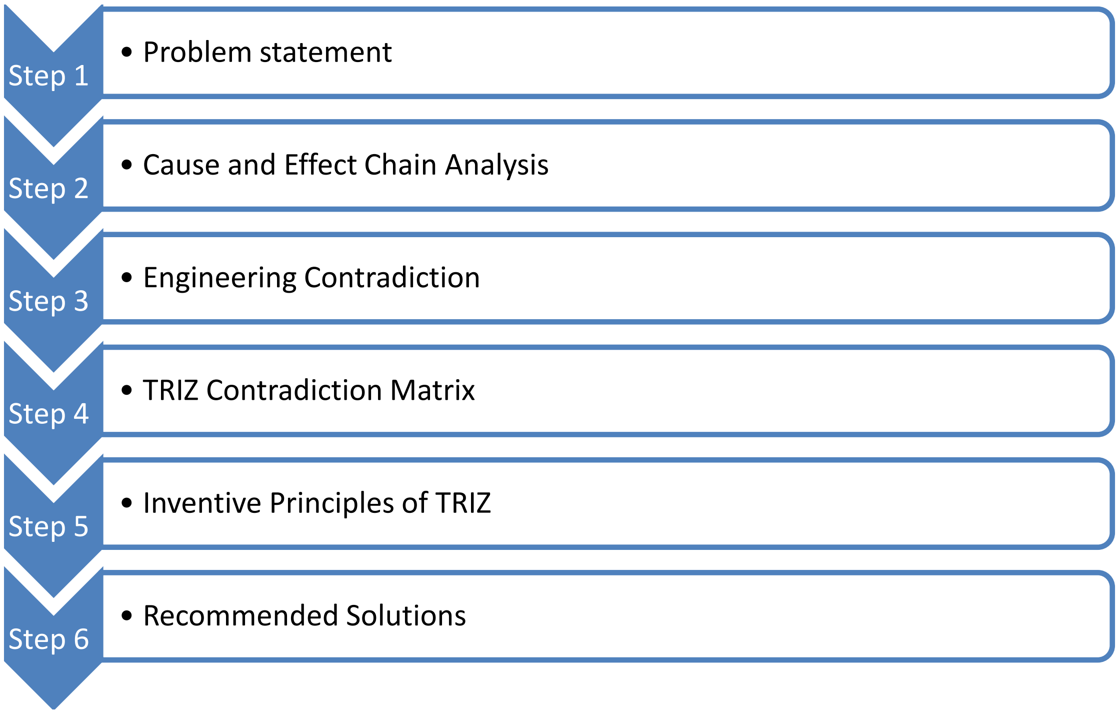

Figure-1. TRIZ methodology used in this research project.

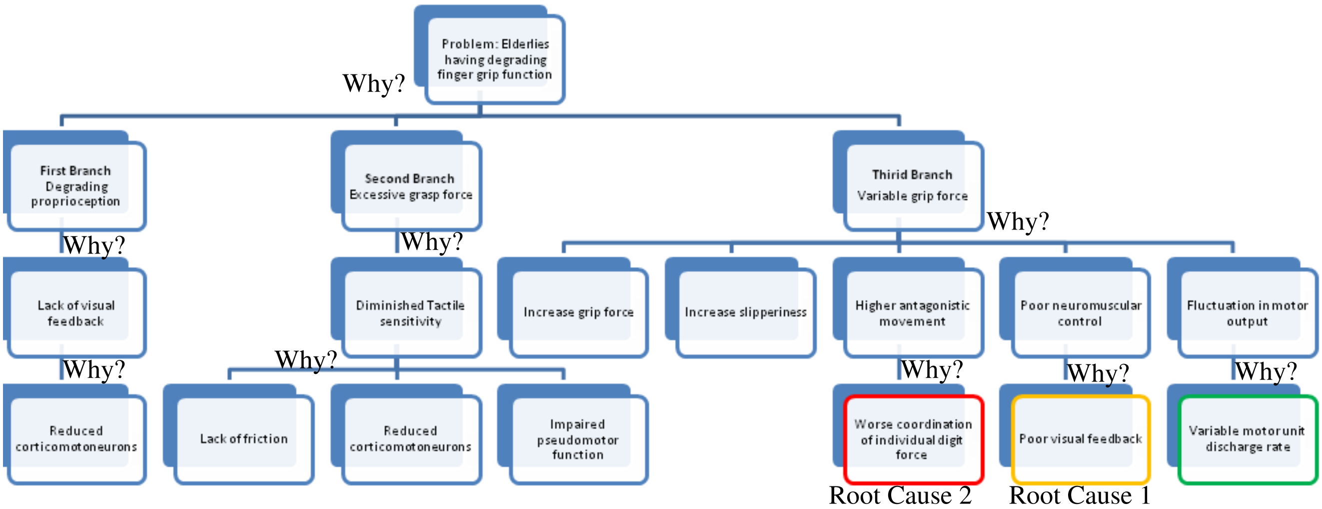

Figure-2. Cause-and-effect-chain analysis diagram (first half).

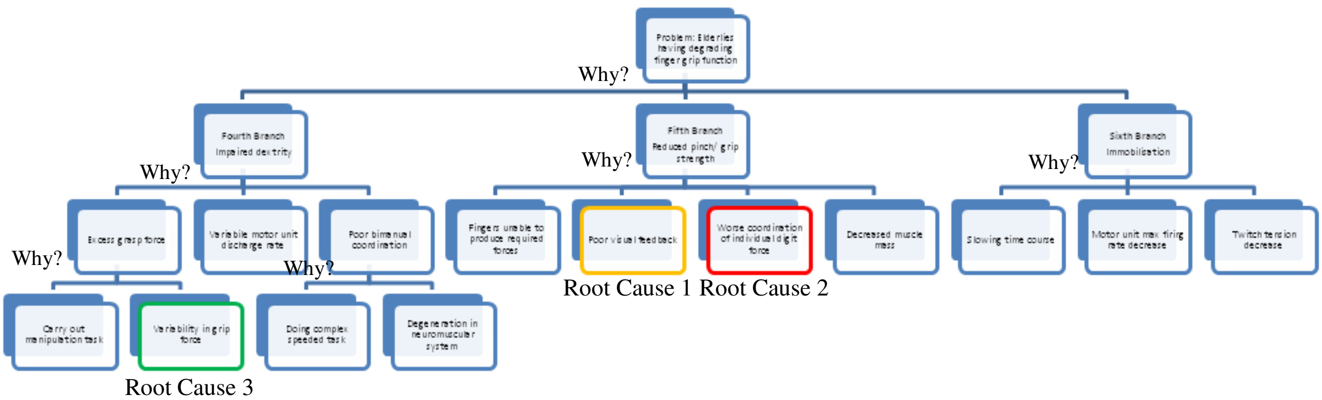

Figure-3. Cause-and-effect-chain analysis diagram (second half).

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As the CEC analysis is being drafted, literature support from field experts is crucial as validation to each possible cause. From the many branches in the Figure-2 and Figure-3, multiple factors contribute to poor finger functions of the elderlies. However, due to the sheer number of literature and research conducted on the third branch (variable grip force/ force control) in Figure-2, fourth branch (impaired dexterity) in Figure-3 and fifth branch (Reduced pinch/ grip strength) in Figure-3, the search for the likely root cause of the problem has been narrowed down to allow more in depth and focused research. The highlighted boxes in Figures 1 and 2 represent the selected root causes of the sub-problems because they are fundamental key disadvantages, repeated in different branches and strongly supported by studies and journals. Hence, at the end of the CEC analysis, the following root causes are obtained:

Root causes 1: Poor-visual feedback (yellow highlight in above diagram)
Root cause 2: Worsening coordination of individual digit force (red highlight in above diagram)
Root cause 3: Variability in grip force and motor unit discharge rate (green highlight in above diagram)

The next step of TRIZ analysis would be to establish engineering contradictions based on the root causes. A 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)

The MATRIZ method was chosen to construct the contradiction because MATRIZ focuses on the positive outcome which is the "then" section. The "then" is normally a reversal of the original problem or one of its sub-problems (causes or key disadvantages) to a positive. After establishing the "then" part, the "if" section can be addressed with a possible obvious solution, followed by the "but" section, since a possible obvious solution would definitely have a flaw in its implementation somehow. The MATRIZ method is more straight-forward because it focuses on the original problem. Using the MATRIZ Method on the three root causes, three engineering contradictions were constructed as such:

Sub-Problem 1: Poor-visual feedback

Engineering Contradiction 1:
If feedback regarding applied force is received while pinching,
Then elderlies would have more information regarding required applied force,
But existing dials or digital displays are not able to effectively transfer information to elderlies.

Many elderlies experience a decline in vision and hearing abilities. With poor eye sight, designing a tool which can substitute visual feedback is necessary(Azir, Zulisman, & Naim, 2014; Zulkifli, Mazida, Juliana, & Ruzinoor, 2015). Currently, dynamometers are the most popular tool to measure finger strength because of its accuracy and simple operations. However, these tools either use a traditional dial or a digital display which becomes ineffective when elderlies have poor eyesight (Lin et al., 2019; Weinstock-Zlotnick et al., 2011). This would result in reduced hand grip force and stability control. Other alternatives to visual feedbacks are required to continually provide information to the user even if the eyesight starts to deteriorate. The second engineering contradiction is constructed as such:

Sub-Problem 2: Worsening coordination of individual digit force

Engineering Contradiction 2:
If extended "fingers" with latching abilities, which can avoid wrongful application of force (more/less), are used,
Then elderlies would have better strength for activities of daily living,
But the safety of elderlies may be at risk as impaired tactile sensitivity between the finger and device could cause stress to fingers.

Although extended "fingers" with latching abilities could assist in better application of force, the interaction between fingers and the device are still dependent on friction for proper force output. With poor tactile sensitivity, elderlies might still have difficulties to operate these devices. A study on this topic was conducted in 2016 which showed a decrease in force flexibility and an increase in shear force when tactile sensory inputs were blurred (Li, Wei, & Yue, 2016). This was the finger muscles response to guarantee a stable grip control of objects. In another study by the same authors, tactile deficits were found to increase in inter-digit centre of pressure distribution (Li *et al.*, 2016). These are important considerations to the design of a suitable tool. The third engineering contradiction is proposed as such:

Sub-Problem 3: Variability in grip force and motor unit discharge rate

Engineering Contradiction 3:
If a mechanism is added to assist in applying steady force on objects,
Then elderlies would have better control when pinching objects,
Butthere would be more discomfort as the mechanism might strain the already-reduced muscles.
A large number of elderlies will experience reduced muscle mass and motor unit losses (Doherty, 2003;

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Larsson & Ansved, 1995). Therefore, any form of device design has to be ergonomic and extremely safe for elderly use. Additional mechanisms could cause damage to old people as they have lesser muscles and a more fragile body in general.

After establishing the engineering contradictions, 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. A contradiction matrix is used to obtain a set of recommended inventive principles to resolve an engineering contradiction. The contradiction matrix was designed to formalise and facilitate the usage of inventive principles. The inventive principles can be extracted from the contradiction matrix by first identifying the appropriate TRIZ system parameters linked to the engineering contradictions. There are a total of 39 TRIZ system parameters.

Tables 1 and 2 present the system parameters and inventive principles for the first engineering contradiction. The outcome of the possible design aims to be an ergonomic finger grip enhancer that provides pinching force feedback. With this in mind, the inventive principle of Mechanics Substitution/another Sense was selected.

Table-1. System parameters for engineering contradiction 1.

Engineering Contradiction Variables	System Parameters
Improving Variable	#27 Reliability
Worsening Variable	#24 Loss of Information

Table-2. Inventive principles from system parameters of engineering contradiction 1.

Pairs of System Parameters	Inventive Principle
#38 & #15	#10 Preliminary action/ Prior action #28 Mechanics substitution/ Another sense

Tables 3 and 4 show the system parameters and inventive principles for the second engineering contradiction. The outcome of the possible design aims to be an ergonomic finger grip enhancer that ensures an appropriate application of force. The inventive principle of dynamisation was selected.

Table-3. System parameters for engineering contradiction 2.

Engineering Contradiction Variables	System Parameters
Improving Variable	#10 Force
Worsening Variable	#11 Pressure/ Stress #22 Loss of Energy

Table-4. Inventive principles from system parameters of engineering contradiction 2.

Pairs of System Parameters	Inventive Principle
#10 & #11	#18 Mechanical vibration #21 Skipping/ Hurrying #11Beforehand cushioning/ Prior cushioning
#10 & #22	#14Spheroidality- curvature #15 Dynamization

Tables 5 and 6 show the system parameters and inventive principles for the third engineering contradiction. The outcome of the possible design aims to be an ergonomic finger grip enhancer that assists in providing steady force. The inventive principle of Parameter Changes was selected.

Table-5. System parameters for engineering contradiction 3.

Engineering Contradiction Variables	System Parameters
Improving Variable	#13 Stability of Object's Composition
Worsening Variable	#11 Pressure/ Stress

Table-6. Inventive principles from system parameters of engineering contradiction 3.

Pairs of System Parameters	Inventive Principle
#37 & #23	#2 Taking Out or Extraction #35 Parameter changes #40 Composite materials/ Composite structure

5. RESULTS AND DISCUSSIONS

Mechanics substitution/another sense

This is a suitable principle to resolve contradiction number one which is related to poor visual feedback among the elderlies. The degrading eyesight has a big influence on how our fingers function. Therefore, it is forward-thinking to consider other forms of mediums in which information regarding finger gripping can be easily processed by the elderlies. The arm motor networks were found to readily incorporate audio feedback and adapt to force with it as well as they did to visual feedback (Oscari, Secoli, Avanzini, Rosati, & Reinkensmeyer, 2012). With some practice, auditory feedback could assist day-to-day activities and prevent household accidents. Some studies also suggest the possibility of it becoming a substitution to visual sensors (Levy-Tzedek, Hanassy, Abboud, Maidenbaum, & Amedi, 2012; Portnoy, Halaby, Dekel-Chen, & Dierick, 2015). Auditory feedback, like an alarm or buzzer, could be a suitable component to assist in monitoring and providing feedback to elderlies. With

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pressure sensors attached to finger tips, the buzzer will trigger once the required pinching force has been achieved and it will buzz again if the user exceeds the required force. This will ensure elderlies pinch with the adequate amount of force to prevent finger injuries.

Dynamization

Because of poor coordination of individual digits, the elderlies have trouble applying the appropriate amount of force. This would mean that they may exert too much force onto the object or apply insufficient pinching force. Both situations would cause accidents or injury to the fingers. From Figure-4, a special tool has been attached onto the toothbrush to provide a better grip for brushing action. NuMuv Grip-Aid is a device that aids people with grasping issues (Obmaces, 2015). It is targeted to help people with rheumatic disease. In association with this invention, a suitable tool could also be developed to help elderly people in pinching objects more effectively. Using this inventive principle, the object which is usually stationary could be designed to be more interactive with the fingers. Some type of latching mechanism would allow the object to hold or hook onto the fingers which would allow users to carry out pinching activities without totally relying on finger strength.

Figure-4. NuMuv Grip-Aid, a device for hand mobility issues (Obmaces, 2015)

Parameter changes

As the finger starts to lose its functions, considering other parts of the body to apply force or elevate stress could assist in activities of daily living. According toCCOHS (2016), methods to prevent back injuries while carrying heavy objects include keeping the arms straight, tightening the abdominal muscles and initiating lift with body weight. All these strategies are meant for the utilisation of other muscles of the body to lift the object while removing stress from the lower back although this example refers to a lifting strategy, the analogy of it can be adopted in this inventive principle to change the parameter of finger pinching activities.

With reference to the aforementioned analogy, a device that clamps an object could provide steady force to its user. The device should also rest on the whole palm or the wrist to avoid injuring the fingers. However, care must be given to ensure that additional tools do not cause more injuries because if tools do not properly accommodate different hand postures, it could lead to serious injuries and development of musculoskeletal disorders (Tan, Ng, Saptari, & Jee, 2014). In January 2019, as seen in Figure-5, Panasonic announced the introduction of an exoskeleton “power wear” that assists in bending and stretching of the waist (Panasonic, 2018). The device has powered motors which provides torque at the hips and reduces the stress on the spine. Similarly, a device that activates muscles from other parts of the hands besides the fingers could assist in a more constant application of force.

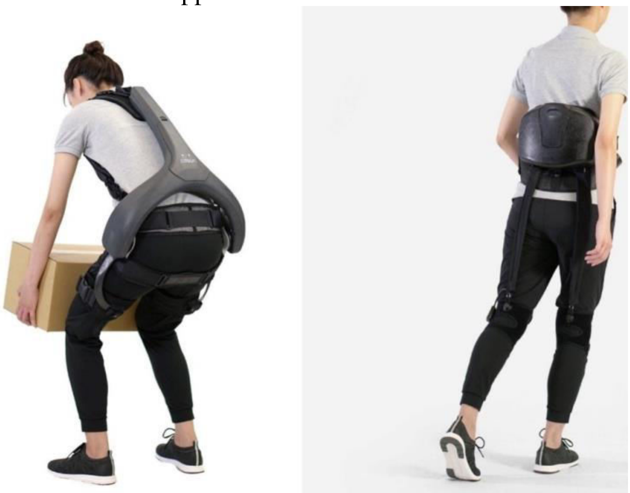

Figure-5. Powered wear” that reduces strain on the back (Panasonic, 2018).

6. CONCLUSIONS

The cause of degrading finger functions among the elderlies is due to biological changes, for examplejoint and vascular diseases, compression of nerves and lower motor neuron syndromes. These causes are inevitable and cannot be prevented. The solution would be to delay these changes or utilise additional supportive tools which can maintain the living standards of elderlies.

A device can provide the support needed to assist in finger gripping for elderlies. With a proper ergonomic design, elderlies would be able to have a strong, steady, consistent pinch with sufficient feedback with regard to pinching force. Using the TRIZ methodology, useful inventive principles like mechanics substitution, dynamisation and parameter changes can act as preliminary strategies that steer the design and development of this finger grip tool towards the right direction.

Nevertheless, it is unknown as to whether the design of this finger pinch assistance tool would beable to solve the root of the problem due to the fact that biological changes are irreversible. Therefore, more researches and tests are required to ensure that this device would be an improvement to the lives of users and not merely a fancy machine. Careful studies should be carried out in the future to ensure the device does not become a burden to the fingers of users.

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