Applied Engineering
2024; Vol. 8, No. 1, pp. 47-60
https://doi.org/10.11648/j.ae.20240801.15

Research Article

Development of a New and Mechanically Intelligent Anti-Tremor Utensil

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Abstract

People living with Parkinson's disease or with essential tremors face many obstacles in their everyday lives. Being able to eat independently is one of them. Many technologies already exist to help people who have difficulty eating independently. However, following a review of existing devices with a team of occupational therapists, it was found that many commercially available solutions were either unhelpful or too expensive. The need for better adapted solutions was obvious so an iterative design methodology based on the user's needs was followed to create a new anti-tremor utensil. The starting point of the design was to analyze the existing utensils to understand better the pros and cons of the available solutions. During the iterative design methodology, several prototypes emerged and led to the creation of the final spoon prototype presented in this paper. A total of 5 different adaptative spoons were designed and are presented in this paper. A sensor-based frequential analysis combined with an occupational therapist review indicates that the proposed prototype is effective against certain types of tremors and that it could potentially help people living with tremor while they eat. The next step of the development will be to test the new prototype with potential users.

Keywords

Occupational Therapy, Anti-Tremor Spoon, Assistive Eating Device, Essential Tremor, Parkinson Disease

1. Introduction

The proportion of individuals living with incapacities grows exponentially with age: people who are 44 years old and underrepresent less than 10% of people living with incapacities; this proportion grows exponentially as individuals age, and for those over 75, 42.5% live with incapacities [1]. Movement disorders, such as tremors, are one of the incapacities affecting the elderly. The most frequently occurring movement disorders are tremors caused by Parkinson's disease, which affect approximately 1M people in the US [2] and 55,000 people in Canada [3] and essential tremor, a neurological disorder that affects mainly the hands, which is experienced by 7.01M people in the US [4] and 1.14 M people in Canada [5]. The inability to use one's arms and hands to grasp, handle, and move objects considerably limits the tasks individuals can accomplish in everyday life, at work and while pursuing hobbies. Most elderly people living with upper limb

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Received: 23 March 2024; **Accepted:** 29 April 2024; **Published:** 17 May 2024

tremor require the daily assistance of a caregiver to accomplish basic tasks such as eating [6]. The inability to eat independently limits the possibility of those living with tremors to continue to live autonomously, a situation that accelerates transfer to nursing homes. The resulting loss of autonomy can affect their well-being, self-confidence, social participation and quality of life in general. People with tremors tend to avoid eating with others to hide their disability. Even if assistive technologies (ATs) are currently available, many people living with disabilities do not have access to the appropriate ATs to meet their daily needs and must therefore depend on help from family or remunerated caregivers to perform many activities [7, 8]. The main factor influencing access to ATs is the high cost of assistive devices [1, 9-11]. Other reasons are that ATs are often complex to use, don't work well enough, or don't fit the user's needs. As a result, users tend to abandon ATs [8, 12].

Currently, elderly people living with upper limb tremors generally try to eat on their own, which can be a long, difficult and energy-consuming process, or ask caregivers or family members to help them [13]. Caregiver assistance requires time and resources, and availability of caregivers may be limited by labor shortages in the health sector [14, 15]. This situation is likely to worsen as the population ages: in the near future, we will have to collectively care for more and more people living with physical incapacities with a smaller workforce [16, 17]. Indeed, demographic data show that the number of individuals over 60 will grow from 841 million people in 2013 to 2 billion people in 2050 [18]. In Canada, the proportion of the population over 65 will grow from 15.6% in 2014 to 23% in 2036 [19]. In the USA, this proportion will grow from 15.2% in 2016 to 23.4% in 2060 [20].

Medical approaches designed to reduce the impact of physical incapacities and help people regain their autonomy tend to focus on finding the root causes of the diseases and addressing them with medication, surgery or cerebral stimulation [21]. Although research on these approaches is necessary, they have many practical issues (e.g., side effects, habituation, low success rates, and surgical operations on difficult to access brain regions) which make short—and long-term developments very uncertain. In rehabilitation, one commonly used approach to address persistent deficits that limit functioning in daily activities is the use of assistive technologies (ATs) to compensate for the loss of capacity. In fact, in Canada, 81% of people living with disabilities use at least one AT (e.g., a wheelchair, arm support, hearing aid, computer access aid, prosthesis, etc.) [1, 9]. Studies have shown that the use of ATs can increase users' subjective well-being, self-esteem, sense of competence and sense of control over life events [22, 23]. It has also been proposed that social participation could be increased [24].

An effective approach could therefore be the use of ATs (e.g., mechanical or robotic technical assistance) to help people with Parkinson's or essential tremors achieve a greater level of independence. In addition to promoting the independence of the elderly and allowing workers in the health care system more time to accomplish other tasks, the use of ATs adapted for tremors is also likely to influence the overall quality of life for those living with these types of disabilities. There are a number of commercially available ATs in existence designed to facilitate autonomous eating for people living with tremors. A basic solution, presented in Figure 1, is weighted utensils, which have bigger handles and are heavier than normal utensils; these are designed to reduce the amplitude and frequency of tremors. Swivel utensils are also available, like those presented in Figure 2, which can reduce the tremors transmitted to the spoon and help keep the food inside the utensil by providing a rotational degree of freedom between the spoon and the handle. More recently, active solutions have emerged such as the Liftware Steady (presented in Figure 3), a device that uses sensors and motors to compensate for tremors. However, a preliminary study (discussed in detail below) indicates that adoption of ATs is limited by the high cost of devices, difficulties operating them, poor performance, and insufficient adaptation of the devices to the user needs.

2. Preliminary Study

As a preliminary study to determine whether any of the existing solutions address user needs, several assistive eating devices were acquired by the project team. The university team (engineers and occupational therapists) first studied these technologies. We then loaned the devices to a team of occupational therapists (n = 8) from the *Support Program for the Autonomy of Seniors* (*Soutien à l'autonomie des personnes âgées)* (SAPA) of the CIUSSS (Centres intégrés universitaires de santé et de service/University health and social services centres) of the Capitale-Nationale, our project partner. Members of this team were able to try the different technologies to get a firsthand impression based on their clinical experience. Occupational therapists (OTs) from the SAPA team were then able to try these solutions with their clients (n = 10). The academic team attended one of the trials and others were videotaped by the SAPA therapists so that the university team could better understand the pros and cons of each solution. This study was approved by the Research Ethics Board at the <<removed for blinding>>, and informed consent was obtained from each participant. Participants were recruited through the Neurological Disorders Department at the <<removed for blinding>> and from a list of people who had participated in other studies and agreed to be contacted for future research. Following the trials, a roundtable was conducted with the OTs to discuss the advantages and disadvantages of the existing technologies. Through these meetings, we were able to determine that there were several drawbacks with these devices. We also conducted a literature review was also to learn more about progress in this field of research and presented it during the roundtable. Comments from OTs, engineers and end users on the existing solutions are discussed below.

Figure 1. Weighted spoon (https://www.caregiverproducts.com/good-grips-weighted-utensils-3.html).

Figure 2. Swivel spoon (https://www.caregiverproducts.com/swivel-spoon-with-built-up-handle.html).

Figure 3. Liftware Steady (https://store.liftware.com/products/liftware-starter-kit).

The first AT studied is a simple mechanical solution: a weighted utensil [25]. The OTs reported that this type of utensil decreased tremors somewhat when users were trying to eat with it, but not enough for every client to be able to use it independently because it only worked in some cases. Then, three spoons, the Steady Spoon [26], the Elispoon [27], and the Liftware Level [28] were studied. These spoons are designed to maintain the utensil's orientation parallel to the ground. The first two devices are purely mechanical and use counterweights to maintain orientation, the third is active and uses sensors and motors ensure that the desired orientation is maintained. These spoons were designed for people with contractures (movement limitations of their wrists), but advertisements for the device stated that the spoons also helped reduce the effects of tremors. According to the occupational therapists, these devices exhibited very poor performance in terms of reducing the effects of tremors due to the nature of the mechanisms (which are not expressly designed to counteract tremors, are too simplistic and involve too much friction). In the case of the Liftware Steady [29], an active device expressly designed to counteract tremors, the spoon attempts to detect the tremor acceleration (by means of an accelerometer) and quickly counter it using a small motor [30, 31]. Studies have shown that this spoon reduces the effect of tremors [30], and the company reports a number of successful case studies. However, the OTs found that the utensil's performance with SAPA clients was disappointing. Indeed, it worked for some but not all clients, and the performance was lower than expected. In addition, neither the clients nor the OTs felt that the spoon's handle was ergonomic and they didn't like the fact that the device's batteries had to be charged every day. Further, the range of motion the spoon allowed was too limited, and the spoon bounced more when it reached the outer limits of the range. More importantly, this spoon retails for CA$350 (compared to the previously mentioned mechanical spoons, which retail for around CA$65), a price that is generally too high for the target population. OTs have observed, while discussing with clients, that cost has an important impact on the choice the user makes when choosing an anti-tremor spoon. On the extreme high end of the price spectrum are robotic solutions, like the Obi [32], which was designed for people suffering from paralysis. These solutions perform fully automated movements and cost over CA$8,000. Because these solutions are extremely expensive, it would be excessive for people who only need a simpler assistance with their movements to use fully automated solutions like the Obi.

Our preliminary assessment of the currently available technological solutions highlighted the fact that existing devices do not entirely meet the needs of people living with tremors, in terms of either performance or cost. This is a generalized trend in the field of AT. In fact, 27% of AT users indicate that they need at least one AT that they don't own. This proportion rises to 44% among people living with severe disabilities [9, 10]. The main reason is the high cost of Ats [1, 9-11]. Another factor is that many ATs are abandoned by their users because their operations are too complex, their performance is weak, or they have not been sufficiently adapted to the needs of individual users [8, 12].

3. Objectives

The overall goal of the ongoing research is to enable people living with tremors to eat independently, our objective is to develop and validate a mechanically intelligent low-cost anti-tremor utensil. The specific objective of the current paper is to develop a solution that addresses the identified issues. As a constraint, our aim is to pursue a purely mechanical solution in order to develop a low-cost and easy-to-use device (e.g., one that doesn't require the user to manage a battery). Our hypothesis is that the utensil will reduce the effect of tremors, allowing users to eat independently and that this solution will be acceptable to individuals and occupational therapists. This project was a collaboration between a university research team that includes members from the <<removed for blinding>>, a research center affiliated with Laval University; members from one of the <<removed for blinding>>; and a clinical team from the <<removed for blinding>>.

This paper is structured as follows. First, the main characteristics of tremors will be presented to better illustrate the underlying problems. Second, the development methodology followed during the project will be described and the different prototypes created during the process will be presented. Then, the chosen prototype will be presented in detail. The method used to evaluate its effectiveness will be presented and the results will be described and discussed.

4. Tremor Characteristics Important for the Design

The development of an anti-tremor spoon requires knowledge of the origins of tremors and the related movement they cause. First, there are two types of tremors 1) tremors that occur when the person is sitting or lying (resting tremors), which often affect the hands or the fingers, and 2) tremors that appear while the person is in motion (action tremors). The second type of tremor is divided into five subcategories: intention tremors, postural tremors, task-specific tremors, kinetic tremors and isometric tremors [33]. When people are eating, the most frequently occurring tremors are the resting tremor, the intention tremor, and the postural tremor. Intention tremors occur when a person is trying to target something with their hands or fingers, e.g., when the person tries to pick up food from their plate or bring the spoon/fork towards their mouth. Postural tremors occur when the person is trying to hold their hand against gravity, which is what you need to accomplish in order to eat properly. Finally, resting tremors affect people when they are trying to eat because they are sitting. In addition to the types of tremors, there are also different categories: essential, Parkinsonian, dystonic, cerebellar, psychogenic, orthostatic and physiologic tremors. This paper will focus on the essential tremor (ET) and the Parkinsonian tremor (PT). Parkinson's disease is a chronic progressive disease of elderly populations; the mean age at diagnosis is approximately 60 years [34]. The average age of people dealing with ETs is around 70 years [35]. These two categories of tremors are important to consider because they are the main reason elderly people have difficulty eating independently and require the help of a caregiver.

Once the kinds of tremors the utensil will have to isolate or cancel are known, the specific characteristics of these tremors can be analyzed in detail. The main technical information to analyze in relation to the tremors is their amplitude, frequency and direction. In a study of 59 patients living with ET in which the objective was to classify hand tremor amplitude and frequency, researchers found that the mean frequency is 6.24 Hz and that the mean tremor amplitude is 9.4 mm of hand displacement [36]. During data collection for this study, the participant's arms were supported horizontally in front of them, except for the wrist; while this is not the exact situation of someone eating, it gives a good approximation of the tremor characteristics. Another study performed using a different protocol concludes that the range of ET is from 4 Hz to 8 Hz, which validates Calzetti's study [37]. In Woods' experiment, participants had to hold a mobile phone and keep their arms in the air without support while performing different tasks, which requires basically the same effort as eating. In the Woods et al. study, the researchers replicated Calzetti's experiment on people living with Parkinson Disease and found that the frequency range of the tremors was 3 Hz to 6 Hz. These data will be useful in evaluating the effectiveness of the anti-tremor spoon and during the development process. However, neither of these studies provides information about the direction of the tremors.

Studies on tremor direction are rare; the only ones found were on subjects living with ET who were asked to draw spirals on sheets of paper. A study found that an axis with a characteristic orientation is present in most patients with ET [35]. However, the goal of the study was to distinguish ET from dystonia cases and not to rate tremors axis in different tasks. To learn more about the tremor orientation, we analyzed several videos of people living with ET or PT eating or doing similar tasks to find a common tremor direction or axis Although this method gave us some idea of the tremor axis, it was not very robust [38-43]. Only 11 clips in which an axis could be identified were analyzed and the tremor axis was not the same in every case. In addition, when a tremor axis was observed, other smaller movements in different directions were occurring simultaneously, which did not make the task easy. In the videos we watched, the dominant axis observed was the pronation/supination (pro/supi) axis, which is along the forearm. The pro/supi tremor movement was also noted by an occupational therapist observing one of her clients. Tremor origins can be located in the shoulder, the elbow or the wrist, which creates complex hand movements. The fact that there are different tremor axes forced development of our solution towards designing a device that would address more general tremor control, i.e., one that would work with different tremor frequencies and orientations.

5. Methodology

We began the development process by trying out the different spoons available for people living with tremors. These spoons were analyzed to learn more about why they did or didn't work well. A brainstorming session was then conducted to discuss different ideas about what could help people living with tremors to eat independently. From the discussions that emerged in the roundtable discussions with the OT team, we explored different solutions, and developed an assistive device prototype through an iterative process in collaboration with OTs and researchers in engineering and rehabilitation, through an approach based on Design Thinking (a user-centered approach that places the individual and his/her needs at the center of the reflection and involves active participation of the user in the innovation) [44]. The prototypes created in this process were produced using the Form 2 printer from *Formlabs*. The different solutions are presented here, along with their advantages and drawbacks. The solution we finally adopted is presented in greater detail.

6. Prototypes Presentation

6.1. Prototype 1 - Swivel Spoon

The first proposed prototype is a 1-degree-of-freedom (DoF) swivel spoon (shown in Figure 4). The working principle is relatively simple: one small bearing inside the handle allows the spoon to rotate freely around the handle axis (axis Z). A distance of 60 mm separates the spoon from the axis of rotation. The fact that the center of mass of the spoon is below the axis of rotation ensures that the spoon remains vertically under the axis of rotation in the static condition; this prevents food from falling off the spoon. The swivel spoon works well in terms of stabilizing the spoon in a neutral position. However, one disadvantage of this configuration is that it only counteracts vibrations in 2 directions: X translations and rotations around the Z-axis. Another downside is that users have to raise their hands higher than their mouths in order to eat the food.

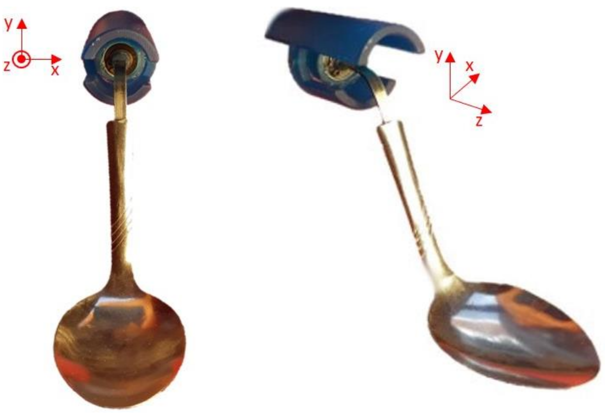

Figure 4. *Swivel spoon prototype.*

6.2. Prototype 2 - Four-Bar Mechanism Spoon

The prototype shown in Figure 5 is an attempt to create a behavior similar to that of the swivel spoon (isolating x-axis translation and z-axis rotations), but with one main improvement. Indeed, even though the swivel spoon design works in terms of maintaining the spoon in a horizontal orientation under static conditions, the spoon oscillates around the Z axis in the dynamic condition. When this occurs, the spoon is not horizontal (as shown in Figure 5) since it follows a circle around the handle axis. With the four-bar mechanism, instead of following a circular trajectory, the spoon follows the trajectory directed by the configuration of the four-bar mechanism. As shown in Figure 6, the spoon with the four-bar mechanism has a virtual center of rotation that is higher than the mechanism itself. This has two advantages. First, it remains closer to the horizontal throughout a wider range of dynamic movements (as shown in Figure 6). Second, it allows the user to maintain the spoon and the handle at the same height. In this design, a weight was installed under the spoon to stabilize it. Another concept that was generated in relation to this design was to add a damper and a spring inside the four-bar mechanism to eliminate the effects of vibration. However, the behavior of the spoon was not as effective as expected; the friction present in the assembly's joints was too high and the movement of the mechanism was not smooth enough. The overall performance was thus weaker than the swivel spoon.

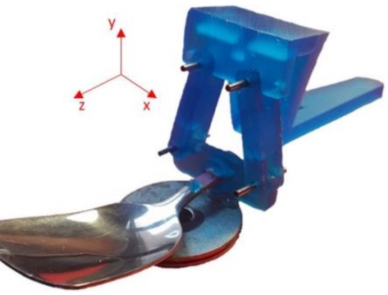

Figure 5. *Four-bar mechanism spoon prototype.*

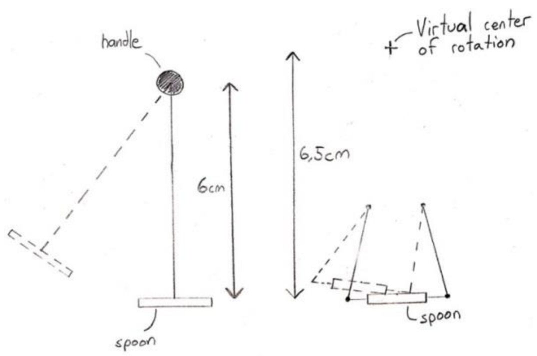

Figure 6. *Swivel spoon trajectory (left) and four-bar mechanism trajectory (right).*

6.3. Prototype 3 - Balanced Spoon

While prototypes 1 and 2 focused on X translation and rotation around the Z-axis, prototype 3 focuses on rotations about the X-axis. The prototype presented in Figure 7 has one rotational DoF that is ensured by two pins located inside the handle, as indicated by the red line in the figure. This axis is aligned with the pro/supi movement of the arm (axis X), which is the most common tremor orientation. This way, if the user has pro-/supi-oriented tremors, the handle will follow the user's tremors, but it won't transfer the vibrations to the spoon; the handle and the spoon are independent of rotations along the joint axis. If the pro-/supi-axis and the joint axis were not aligned, the pro/supi tremors would create a translational movement directed towards the joint which would be harder to isolate. This is why the joint is located inside the handle. However, the main drawback of this prototype is that the handle must be larger. The main challenge with this DoF is that the spoon must be balanced; otherwise, the utensil will simply fall. Balancing the spoon is easy; however, the spoon's content (food) is always different. To balance the prototype, a counterweight was installed on the other end of the utensil; this brings the center of gravity lower than the X-axis and aligns with Y-axis. This allows the handle to rotate around X-axis freely without transmitting the movement to the spoon. Under static conditions, the spoon remains in a horizontal orientation regardless of the handle orientation to avoid spilling the food, as presented in figure 8. From ad hoc tests, the prototype worked well in terms of reducing the effect of vibrations, but only for tremors in one direction. An important challenge with balancing the spoon against gravity is that if the food scooped into the spoon is too heavy, because the prototype is balanced with counterweights, the orientation of the utensil may no longer be horizontal.

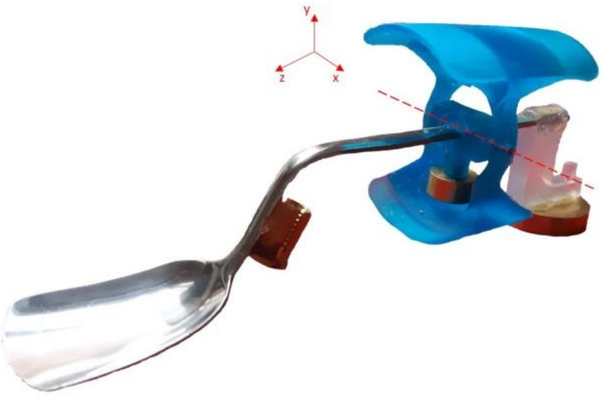

Figure 7. *Balanced spoon prototype.*

Figure 8. *Balanced spoon prototype with 2 different handle orientations.*

6.4. Prototype 4 - Swivel and Balanced Spoon

Prototypes 1, 2 and 3 focused on one DoF at a time. Prototype 4 combines prototypes 1 and 3. Figure 9 shows the prototype with 2 DoFs, in which a rotation is allowed by two small pins located just outside the bearing (along the X-axis) and the swivel is ensured by a bearing (aligned with the Z-axis). This prototype reduced the effect of tremors acting around both the X- and Z-axes. However, this prototype has some drawbacks. First, the handle is big and difficult to grab because the rotation joints are located inside the handle. In addition, the swivel rotation was unstable because the distance between the swivel's axis of rotation and the spoon was too small. This is an important design parameter because if this distance is longer, the movement will be more stable but the user will have to raise his/her hand higher to bring the spoon to his/her mouth. If this distance is too short, a small tremor might lead the spoon to high angles of rotation.

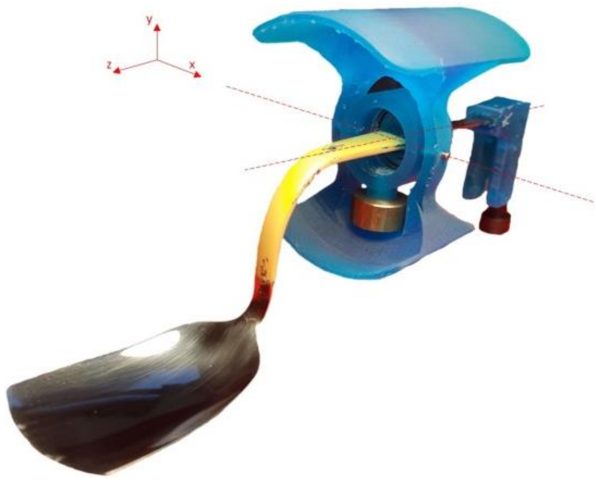

Figure 9. *Swivel and balanced spoon prototype.*

6.5. Final Prototype - Spherical Balanced Spoon

The final prototype, presented in Figures 10 to 12, is designed to have the same DoFs as prototype 4 but with major changes that will be detailed here.

Ergonomics findings from the initial evaluation of commercial devices revealed that the handle needed to be small to be comfortable. With the proposed prototype, a smaller handle than the previous prototype was designed (labelled "A" on Figure 11). To reduce the handle's size, the rotation joint, between parts B and C, had to be placed outside the handle. The joint was moved to one side to keep the axis aligned with the pro/supi movement orientation, represented by axis 1 on figures 10 and 11. The first DoF is ensured by a bearing linking the handle part of the prototype (A and B parts) to the upper arch (C). The second DoF is ensured by a pin that links part C to parts D and E, with parts D-E moving together. Part F is a stopper that maintains the arches D-E within a given range. Part G is also a stopper; it blocks the rotation when the user tries to pick up food from the plate; otherwise, the utensil would maintain a horizontal orientation and it would be hard to pick up the food.

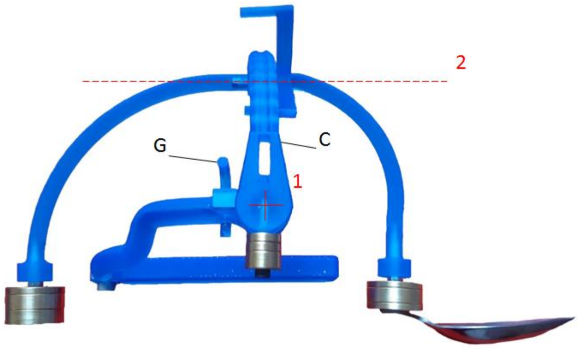

Figure 10. *Side view of the final prototype.*

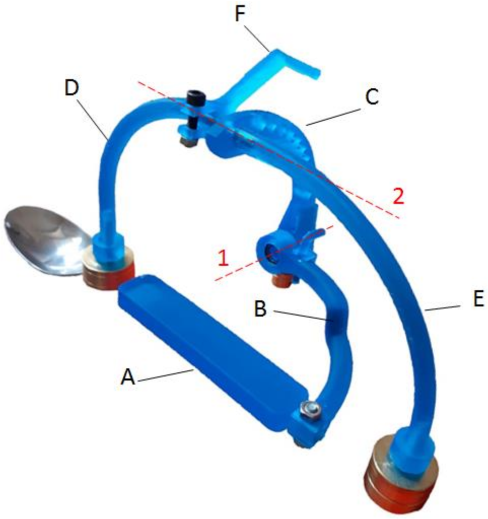

Figure 11. *Isometric view of the final prototype.*

To obtain better stabilization performances than commercialized solutions, the mechanism had to be balanced. In order to balance the mechanism, the center of mass of parts C-F-D-E has to be lower than the axis of rotation 1. Also, the center of mass of parts D-E has to be lower than axis 2. To make it possible, brass counterweights are fixed on parts C-D-E. Because of these added weights, the spoon remains in the same orientation even if the handle rotates. To lower the center of mass even more and make the mechanism more stable, part C has several holes in it to make it lighter. In order to make the mechanism more stable than prototype 4, the distance between the spoon and the axis of the second DoF is 7.5 cm longer (11 cm versus 3.5 cm). As seen in the side view, arches D and E don't have the same shape; the arch that supports the spoon has the same vertical dimension, but it is not as wide horizontally. This brings the spoon closer to the rotation axis and reduces the impact of the food's weight on the center-of-mass position. This way, the food applies less torque around axis 1 and has less impact on the spoon's orientation. Figure 12 show how the prototype is held and which hand rotations are compensated. The final spoon developed offers a larger range of angular hand movement than existing commercial devices. The presented prototype has been 3d-printed, when the anti-tremor spoon is going to be commercialized, it will rather be made by molding, which is cheaper for bigger quantities. The estimation of the unit cost is around 10$, for a production quantity of 5000 spoons.

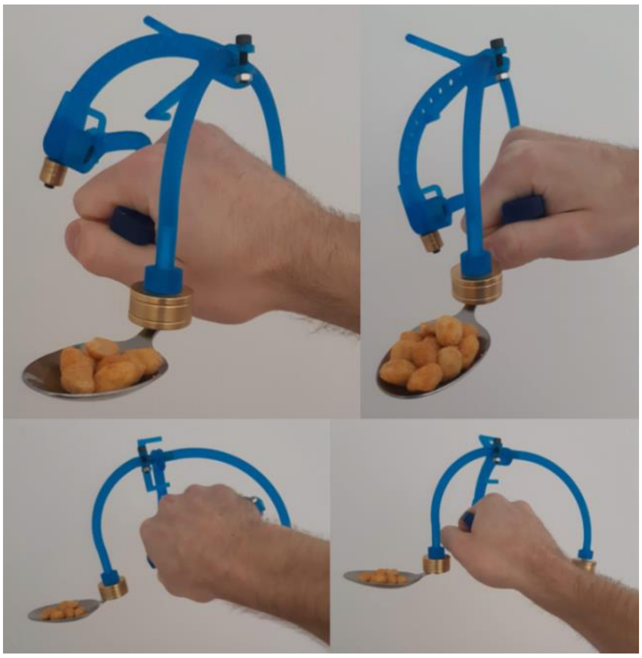

Figure 12. *Different positions of the spherical spoon prototype.*

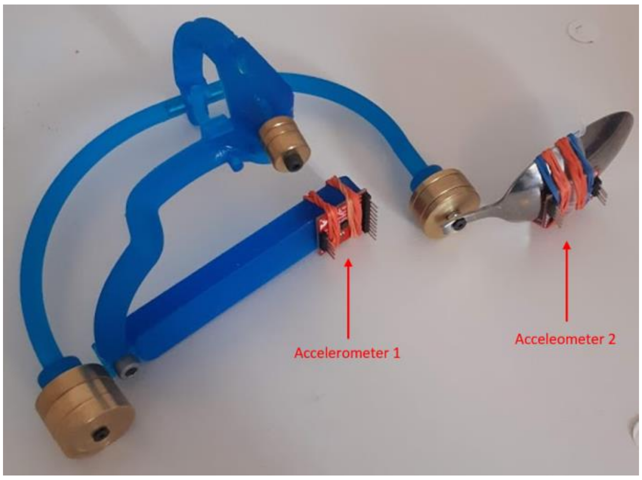

Figure 13. *The accelerometers installed on the final spoon prototype.*

Finally, table 1 compares the functionalities of the spherical balanced spoon with the functionalities of the existing commercial solutions.

Table 1. Comparison between final developed spoon and existing solutions.

Spoon model	Characteristics
Final prototype – Spherical balanced spoon	Two degrees of freedom between the spoon and the handle (it means the handle can move/rotate in two directions without affecting the spoon) The spoon is balanced and stays in the same orientation.
Weighted spoon (Figure 1)	Zero degree of freedom between spoon and handle. The weight lowers the natural frequency of the spoon, which lowers the impact of tremors.
Swivel spoon (Figure 2)	One degree of freedom between spoon and handle.
Liftware Steady (Figure 3)	Two degrees of freedom between spoon and handle. Contains motors and sensors.

7. Vibration Testing

7.1. Methodology of Vibration Testing

In order to quantify the efficiency of the final prototype, the spherical spoon was tested using two accelerometers. The translational acceleration in three directions (a_x, a_y, a_z) was read from each Inertial Measurement Unit (IMU). As presented in Figure 13, one accelerometer was installed on the handle and the other was installed on the spoon. This way, vibration input and output can be monitored and it is possible to evaluate the effect of the mechanism on tremor reduction. The spoon was tested by a healthy subject, who is not a potential user living with tremors of any kind, to reproduce different tremors in different directions. Tremor input frequency was verified to respect the average tremor frequency, which ranges from 3 Hz to 8 Hz for people living with ET or PT. The prototype was also tested for frequencies above and below the 3–8 Hz range. Two different tremor orientations were tested independently: pro/supi tremors (around axis-1 of Figures 10 and 11) and translation along the same axis. A low-pass filter (with a cut-off frequency of 30 Hz) was used on the accelerometers' raw data to eliminate the noise present in the signal. The acceleration magnitudes of each accelerometer were compared and a Fast Fourier Transform (FFT) was also performed to get a better understanding of the prototype's behavior with different frequencies. The magnitude of the filtered acceleration vector was calculated for each accelerometer as follows:

$$|acceleration| = \sqrt{{a_x}^2 + {a_y}^2 + {a_z}^2}$$

The fast Fourier transform was performed on the accelerometer data using the built-in FFT function of Matlab®.

Test 1

A pro/supi tremor test was conducted to evaluate the first DoF of the mechanism, which is along axis-1 in figures 10 and 11. The test started with a low frequency movement, then the frequency of the tremor was increased to obtain a general view of the prototype's behavior when subjected to movements with a vast spectrum of frequencies. Results of this test are presented in the next section of this paper.

Test 2

This test was conducted by performing a translational movement of the handle along axis-1 of figures 10 and 11. This object of this part of the experimentation is to observe how the second DoF (axis-2 joint of figures 10 and 11) of the prototype behaves. As with the pro/supi tremor, the test began with a low frequency movement and ended with higher frequency movements to observe the mechanism's response under different frequencies. Results of this test are presented in the next section of this paper.

7.2. Results of Vibration Testing

Results of test 1

Figures 14 and 15 show the acceleration over time results and the FFT analysis of the signal for the first test conducted.

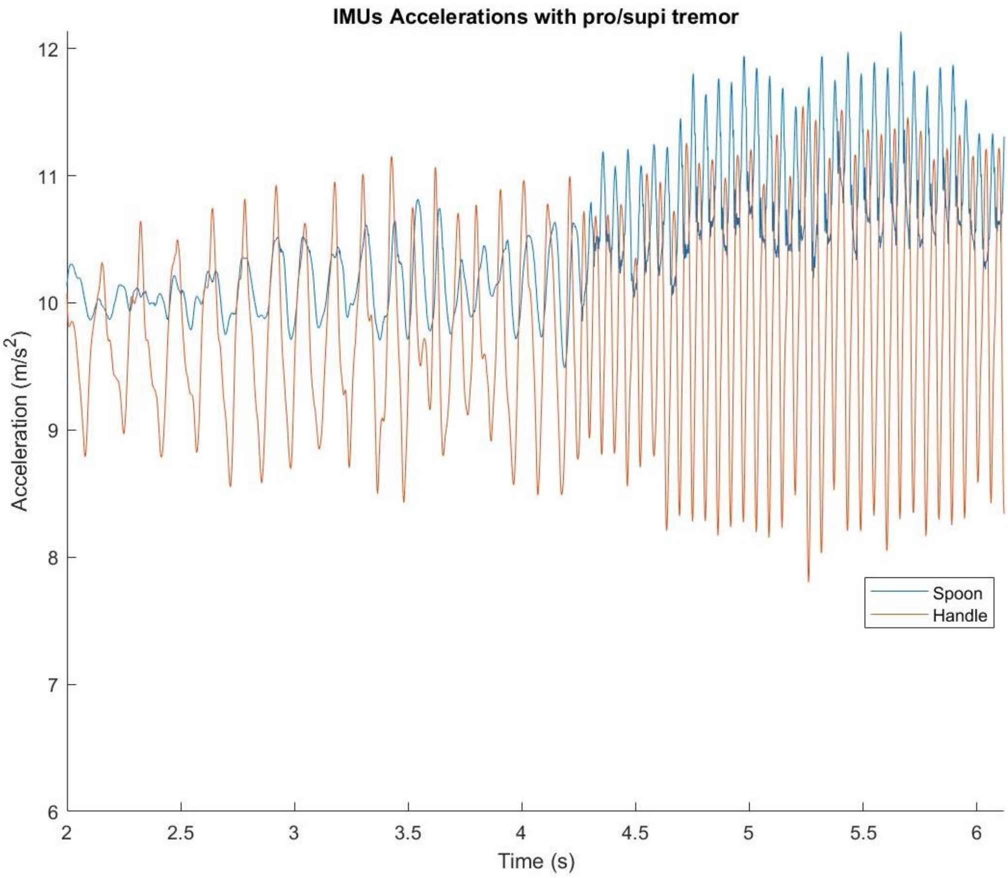

Figure 14. *Graphic showing acceleration over time for the pro/supi tremor test.*

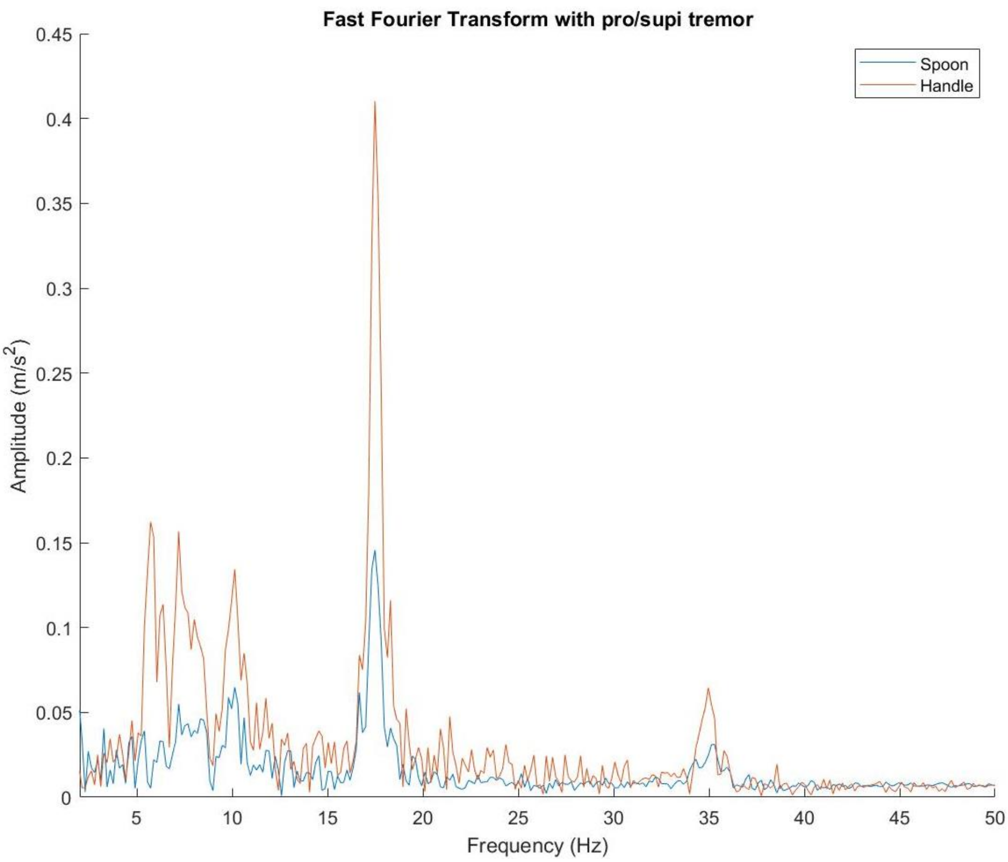

Figure 15. *Graphic showing the Fast Fourier Transform of the pro/supi tremor test.*

As observed in Figure 14, for time <4.25s, the prototype behaved as expected; the variation in the spoon signal is smaller than the handle's signal. For time >4.25s, the variation in the spoon signal is still smaller than the variation in the handle; moreover, the spoon has higher acceleration values. This is caused by the direction of the spoon accelerations. Indeed, the input frequency for time >4.25s excites the spoon in a way that the acceleration translates along the gravity vector while the handle is rotating. Accelerometers read translational accelerations; this is why the spoon values are higher than the handle values for this timeframe. This is acceptable because the spoon maintains the same orientation, which prevents the food from falling even if the spoon moves. In addition, the frequency analysis shown in Figure 15 indicates that the main frequencies present in the handle movement (5 Hz, 7 Hz, 10 Hz and 17 Hz) are all damped by the mechanism. From 5 Hz to 20 Hz, the sum of the amplitude is 6.53 m/s^2 for the handle and 2.73 m/s^2 for the spoon, a 58.19% reduction. This means that the spoon is effective to counteract pro/supi tremors in the interval analyzed.

Results of test 2

Figures 16 and 17 show the acceleration over time and the FFT analysis of the signal for the second test conducted.

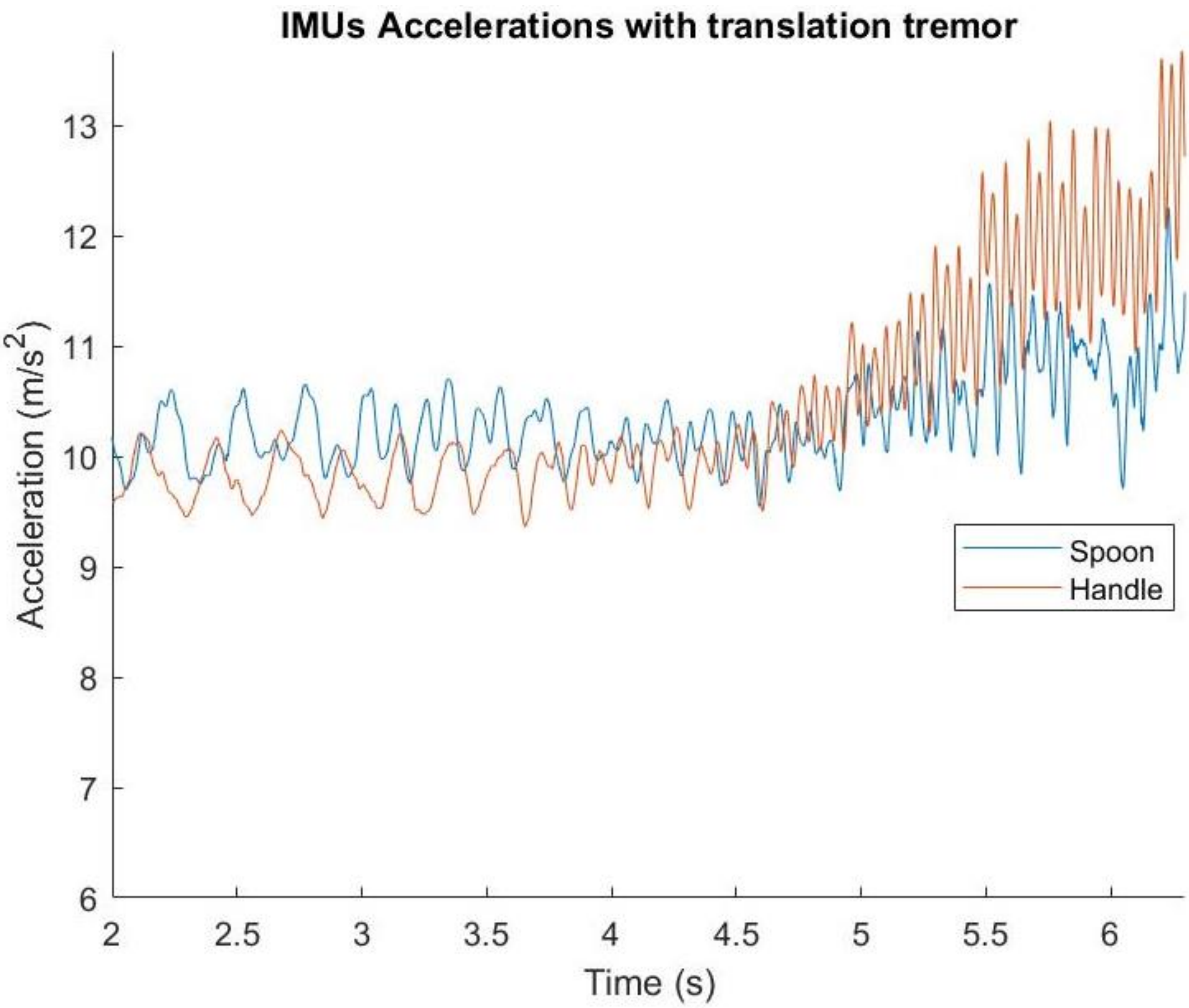

Figure 16. *Graphic showing acceleration over time for the translation tremor test.*

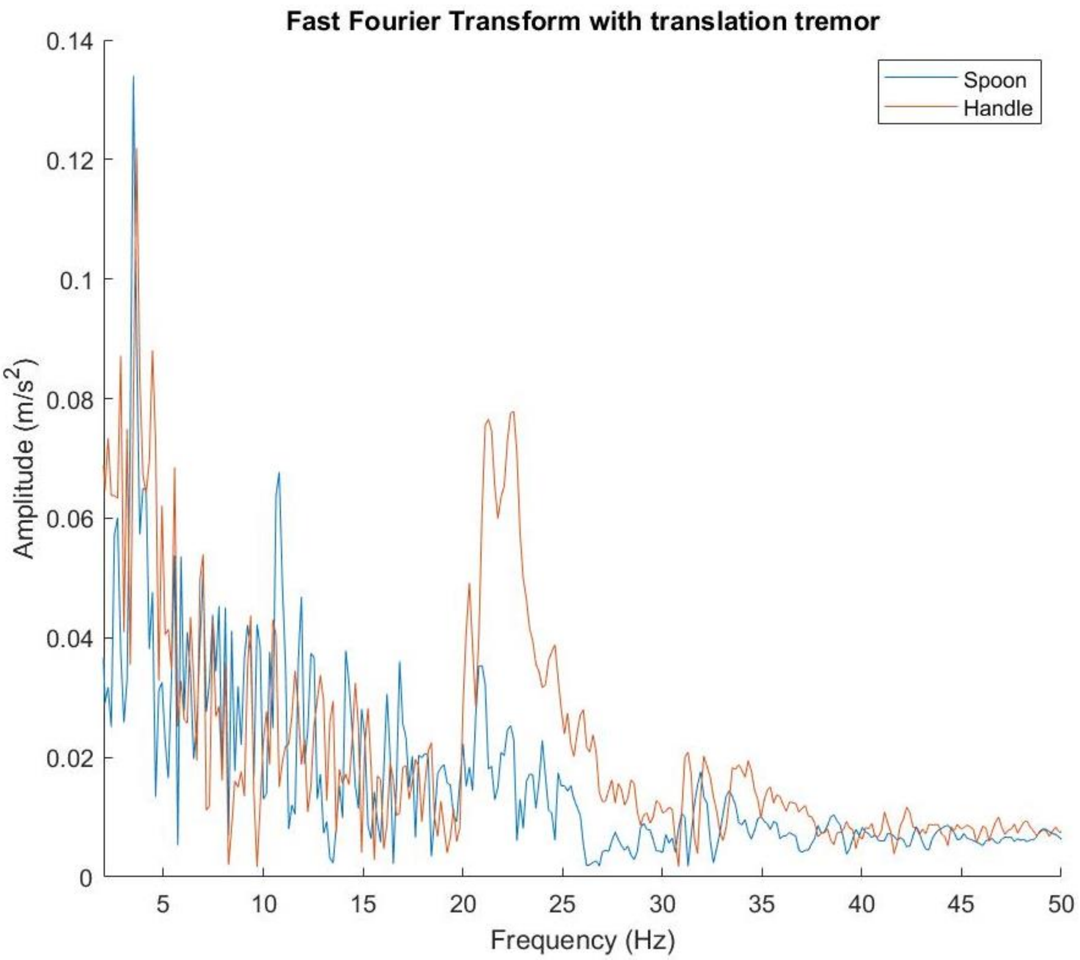

Figure 17. *Graphic showing the Fast Fourier Transform of the translation tremor test.*

As presented in Figure 16, for time <4.5s, which is a low-frequency movement, the prototype did not significantly damp the vibrations. The handle signal and the spoon signal follow each other with a small delay. Figure 17 confirms this and shows that frequencies lower than 20 Hz are not damped. This is not surprising considering that the second DoF of the prototype is a pendulum and that, by moving the center of rotation sideways, the lower part of the pendulum (the spoon) must follow the movement with a certain delay. However, for higher frequencies (>20 Hz), the prototype reduces the amplitude of the vibrations effectively. The fact that the prototype doesn't damp low-frequency vibrations for this direction isn't dramatic; the configuration is made this way so that the spoon always remains in an orientation that prevents the food from spilling. Also, when testing the second DoF with food in the spoon, we observed that the pendulum effect helped keep the food inside the spoon. So, even if the spoon is oscillating, the circular trajectory followed prevents the food from spilling out. From 5 Hz to 20 Hz, the sum of amplitude is 2.09 m/s^2 for the handle and 2.32 m/s^2 for the spoon, an 11% augmentation. From 20 Hz to 40 Hz, the sum of amplitude is 2.86 m/s^2 for the handle and 1.30 m/s^2 for the spoon, a 54.55% diminution. This means that the prototype doesn't counteract tremors in the 5-20Hz interval but is effective in the 20-40Hz interval.

8. Occupational Therapist Review

8.1. Methodology of Occupational Therapists' Review

During the development process, the different prototypes generated were presented to OTs and their comments were taken into account to improve the solutions. Two copies of the final spoon solution were produced and given to different therapists' to test and evaluate.

8.2. Occupational Therapists Review

The OTs mentioned that the main advantage of the final prototype is that it is less expensive than the commercially available solutions that need to be charged (active solutions). Since this is not the final version of the prototype, it is hard to conclusively evaluate the ultimate cost of the final design, but the price will certainly be under CA$100. Another advantage is that the prototype is easy to clean and it is possible to interchange the spoon with a fork.

The main drawback observed with the prototype is that its use is non-intuitive. The prototype presented in this paper doesn't have a classic utensil shape, and it may initially be difficult for users to understand how to hold it. A further drawback observed is that the utensil is not compact enough and would be difficult to transport. The final drawback is that the prototype is not "normalized" for the user, meaning that users may feel self-conscious using the utensil because of its abnormal aesthetic.

9. Conclusion

The results of the vibration tests show that the final prototype counteracts pro/supi tremors effectively for a vast interval of frequencies. However, the solution is not effective to counteract translation tremors with a frequency lower than 20Hz. This is not dramatic because even if the prototype doesn't counteract low-frequency tremors perfectly in this direction, the circular trajectory followed by the spoon prevents the food from spilling out. For higher frequencies of translation tremors, the prototype effectively reduces the amplitudes of vibrations. The frequency analysis show that the prototype's performances are satisfying but it also shows that it would need to be improved to counteract more lower-frequency translation tremors. The occupational therapists review provided important information from a health professional point of view about the performances of the final prototype. The review pointed out different drawbacks (section 8.2 of this paper) that are going to be considered when future iterations of the anti-tremor utensil will be designed. Generating future iterations of the prototype that are more compact and more aesthetic will require the assistance of an industrial design professional. Even if several drawbacks were observed, the final prototype remains in their opinion a good potential option to replace the expensive active solution available on the market.

10. Recommendations

To improve the performances for lower-frequency translation tremors, a possible solution could be to improve the axis-2 joint in order to reduce the friction. The current joint is made of a dowel pin and a slide-fit hole, a bushing could be added to reduce even more the friction. The next step will also consist in testing the device with people with tremors in order to assess the solution in real situation and to improve the device accordingly with the results. Frequency analysis on people living with tremors while using the utensils will give crucial information about the ways to upgrade the solutions presented in this paper.

Abbreviations

DOF: Degree of Freedom

SAPA: Soutien à l'autonomie des Personnes âgées (Support for the Autonomy of Elderly People)

CIUSSS: Centres Intégrés Universitaires de Santé et de Ser-vice (University Health and Social Services Centres)

AT: Assistive Technologie

OT: Occupational Therapist

ET: Essential Tremors

PT: Parkinsonian Tremor

FFT: Fast Fourier Transform

IMU: Inertial Measurement Unit

Acknowledgments

This work is supported by the "Ministère de l'Économie et de l'Innovation" and by Dr. Alexandre Campeau-Lecours' research funds at the <<removed for blinding>> and Université Laval (Québec City, Canada).

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Statistics Canada, "Disability in Canada: initial findings from the Canadian Survey on Disability", 2013.

[2] Parkinson's Foundation, Statistics. Available: https://www.parkinson.org/Understanding-Parkinsons/Statistics#:~:text=Who%20Has%20Parkinson's%3F&text=Approximate-ly%2060%2C000%20Americans%20are%20diagnosed,are%20diagnosed%20before%20age%2050 (Accessed: 04-april-2020)

[3] Ramage-Morin, P. (2014). *Parkinson's disease: Prevalence, diagnosis and impact*. https://doi.org/10.13140/2.1.4842.9767

[4] Louis, E. D., & Ottman, R. (2014). How Many People in the USA Have Essential Tremor? Deriving a Population Estimate Based on Epidemiological Data. *Tremor and Other Hyperkinetic Movements*, *4*(0), 259. https://doi.org/10.5334/tohm.198

[5] Sunnybrook Research Institute, Essential tremor. Available: https://sunnybrook.ca/research/content/?page=sri-centres-focused-ultrasound-tremor#:~:text=Photo%3A%20Doug%20Nicholson.,of%20the%20population%20in%20Canada (Accessed: 04-april-2020)

[6] "La maladie de Parkinson: prévalence, diagnostic et conséquences." [Online]. Available: https://www150.statcan.gc.ca/n1/pub/82-003-x/2014011/article/14112-fra.htm (Accessed: 20-Oct-2020).

[7] S. Federici, F. Meloni, and S. Borsci, "The abandonment of assistive technology in Italy: a survey of National Health Service users.," Eur. J. Phys. Rehabil. Med., vol. 52, no. 4, pp. 516–26, Aug. 2016.

[8] R. Verza, M. L. L. Carvalho, M. A. Battaglia, and M. M. Uccelli, “An interdisciplinary approach to evaluating the need for assistive technology reduces equipment abandonment,” (2006), Mult. Scler. J., vol. 12, no. 1, pp. 88–93.

[9] R. Arim, A profile of persons with disabilities among Canadians aged 15 years or older. (2012) Statistics Canada.

[10] A. G. Dell, D. A. Newton, and J. G. Petroff, Assistive technology in the classroom: Enhancing the school experiences of students with disabilities. (2008), Pearson.

[11] Statistics Canada. Participation and Activity Limitation Survey: Assistive aids and devices for adults, 2008.

[12] M. L. Riemer-Reiss and R. R. Wacker, “Factors associated with assistive technology discontinuance among individuals with disabilities,” J. Rehabil., vol. 66, no. 3, 2000.

[13] Guo, M., Shi, P., & Yu, H. (2017). Development a feeding assistive robot for eating assist. 2017 2nd Asia-Pacific Conference on Intelligent Robot Systems, ACIRS 2017, 299–304. https://doi.org/10.1109/ACIRS.2017.7986112

[14] “Manque criant de personnel dans les CHSLD” [Online]. Available: https://www.lapresse.ca/actualites/sante/2019-09-26/manque-criant-de-personnel-dans-leschsld [Accessed: 06-Nov-2020].

[15] “Plus de 60 000 travailleurs de la santé recherchés | Le Devoir.” [Online]. Available: https://www.ledevoir.com/politique/quebec/553217/mot-cle-besoin-de-60-000-travailleurs-de-lasante-d-ici-5-ans [Accessed: 06-Nov-2020].

[16] H. F. M. Van der Loos, D. J. Reinkensmeyer, and E. Guglielmelli, “Rehabilitation and health care robotics,” (2016), in Springer handbook of robotics, Springer, pp. 1685–1728.

[17] R. Choinière, Vieillissement de la population, état fonctionnel des personnes âgées et besoins futurs en soins de longue durée au Québec. (2010) Institut national de santé publique Québec.

[18] S. Chatterji, J. Byles, D. Cutler, T. Seeman, and E. Verdes, “Health, functioning, and disability in older adults—present status and future implications,” (2015), Lancet, vol. 385, no. 9967, pp. 563–575.

[19] Government of Canada – Action for Seniors report (2014). Available: https://www.canada.ca/en/employment-social-development/programs/seniors-action-report.html (Accessed: 04-april-2020)

[20] An Aging Nation: Projected Number of Children and Older Adults (2018). Available: https://www.census.gov/library/visualizations/2018/comm/historic-first.html (Accessed: 04-april-2020)

[21] A.Q. Rana and K. L. Chou, Essential Tremor in Clinical Practice. (2015), Cham: Springer International Publishing.

[22] M. J. Fuhrer, “Subjectifying quality of life as a medical rehabilitation outcome.,”, (2000), Disabil. Rehabil., vol. 22, no. 11, pp. 481–489.

[23] D. Yachnin, G. Gharib, J. Jutai, and H. Finestone, “Technology-assisted toilets: Improving independence and hygiene in stroke rehabilitation.,”, (2017), J. Rehabil. Assist. Technol. Eng., vol. 4.

[24] J. A. Lenker, F. Harris, M. Taugher, and R. O. Smith, “Consumer perspectives on assistive technology outcomes.,” (2013), Disabil. Rehabil. Assist. Technol., vol. 8, no. 5, pp. 373–380, Sep.

[25] Sure Grip Weighted Utensils | Adaptive Eating Utensils | Performance Health. [Online]. Available: https://www.performancehealth.ca/sure-grip-weighted-utensils [Accessed: 20-Oct-2020].

[26] Performance Health, “Steady spoon”. Available from: https://www.performancehealth.ca/steady-spoons [Accessed: 20-Oct-2020].

[27] Homepage - ELISpoon. [Online]. Available: https://elispoon.com/ [Accessed: 20-Oct-2020].

[28] Liftware Level | Liftware. [Online]. Available: https://www.liftware.com/level/ [Accessed: 20-Oct-2020].

[29] Liftware Steady | Liftware. [Online]. Available: https://www.liftware.com/steady/ [Accessed: 20-Oct-2020].

[30] Pathak, A. J., & Owens, D. U.S. Patent Application No. 10/058,445, 2018.

[31] J. L. Pons, E. Rocon, A. F. Ruiz, and J. C. Moreno, “Upper-limb robotic rehabilitation exoskeleton: Tremor suppression,” (2007), in Rehabilitation robotics, InTech.

[32] Obi – The first dining robot of its kind. [Online]. Available: https://meetobi.com/ [Accessed: 20-Oct-2020].

[33] Hallett, M. (2013). *Parkinsonism and Related Disorders 20S1 (2014) S118-S122 Tremor: Pathophysiology*.

[34] DeLong, M. R., Huang, K. T., Gallis, J., Lokhnygina, Y., Parente, B., Hickey, P., Turner, D. A., & Lad, S. P. (2014). Effect of advancing age on outcomes of deep brain stimulation for parkinson disease. JAMA Neurology, 71(10), 1290–1295. https://doi.org/10.1001/jamaneurol.2014.1272

[35] Louis, E. D., Yu, Q., Floyd, A. G., Moskowitz, C., & Pullman, S. L. (2006). Axis is a feature of handwritten spirals in essential tremor. Movement Disorders, 21(8), 1294–1295. https://doi.org/10.1002/mds.20915

[36] Calzetti, S., Baratti, M., Gresty, M., & Findleyt, L. (1987). Frequency/amplitude characteristics of postural tremor of the hands in a population of patients with bilateral essential tremor: implications for the classification and mechanism of essential tremor. *Consortia. Protected by Copyright. on February*, *50*, 561–567. https://doi.org/10.1136/jnnp.50.5.561

[37] Woods, A. M., Nowostawski, M., Franz, E. A., & Purvis, M. (2014). Parkinson’s disease and essential tremor classification on mobile device. *Pervasive and Mobile Computing*, *13*, 1–12. https://doi.org/10.1016/j.pmcj.2013.10.002

[38] Channels Television, “Gyroscope Gloves Reduces Hand Tremors For Parkinson's Patients”. Available from: https://www.youtube.com/watch?v=eZvvB9WX1Tg&ab_channel=ChannelsTelevision (@ 0:45). [Accessed 28 April 2024].

[39] Brian Allen, ""Smart" Spoon for Parkinson's Sufferers". Available: https://www.youtube.com/watch?v=WiVQcgmIi08&ab_channel=BrianMKAllen (@ 0:06, 0:38, 0:56, 1:14). [Accessed 28 April 2024].

[40] CTOOM Creative, "GYENNO Spoon – Smart Self-Stabilizing Spoon for Hand Tremor and Parkinson's Sufferers". Available from: https://www.youtube.com/watch?v=dVd7M7xuK5w&ab_channel=CTOOMCreative (@ 0:08, 0:13). [Accessed 28 April 2024].

[41] STAT, "Living with essential tremor". Available from: https://www.youtube.com/watch?v=SFnWlqQ1z60&ab_channel=STAT (@ 0:42, 0:49). [Accessed 28 April 2024].

[42] Associated press, "Google Spoon Helps People With Tremors Eat". Available from: https://www.youtube.com/watch?v=99t5c6j8BR0&ab_channel=AssociatedPress (@ 0:12). [Accessed 28 April 2024].

[43] Liftware, "Using Liftware: Berta (Severe Tremor)". Available from: https://www.youtube.com/watch?v=Yn8VDA_I6b8&ab_channel=Liftware (@ 2:33). [Accessed 28 April 2024].

[44] Brown, T., & Katz, B. (2011). Change by Design. Journal of Product Innovation Management, 28(3), 381-383.