

Control design of vibrotactile stimulation on weighted vest for deep pressure therapy



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ABSTRACT

Introduction: This study presents a novel weighted vest integrated with vibrotactile stimulation for deep pressure therapy. Following the principles of Morrison's research, we assessed its effectiveness in calming users with four distinct vibration patterns.

Method: Ten male participants without ASD history, aged 19-25 and weighing 48-73 kg, provided subjective evaluations using the Comfort Rating Scale (CRS).

Result: Results showed that participants reported increased calmness after using the device, as evidenced by the overall ratings of the "calming" term, with the "down" pattern receiving the highest ratings. The study advocates for future work involving physiological sensors to measure the device's effectiveness objectively. While promising, this innovation has limitations, such as fixed vibration frequency and reliance on an adapter for power. Future iterations could address these issues to enhance the device's portability and customizable vibration frequencies.

Conclusion: This research contributes to deep pressure therapy and vibration therapy by focusing on responsive patterns and subjective evaluations, opening doors for future developments.

Keywords: Deep Pressure Therapy, Weighted Vest, Vibration Therapy, Vibrotactile Stimulation.

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INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurological condition characterized by deficits in communication and socialization skills, repetitive behaviors, self-injury behaviors, and challenging behaviors.¹ According to the Ministry of Women's Empowerment and Child Protection of the Republic of Indonesia's data in 2018, it is estimated that there are approximately 2.4 million individuals with ASD in Indonesia, with an additional five hundred new cases each year.² Autism begins in childhood and can be observed in the first weeks of life. It can be found in all socioeconomic classes and across all ethnicities and races. Individuals with autism from early life struggle to engage with others in typical ways. They have limited language abilities and are highly obsessive, preferring routines and monotony in their surroundings.³

Deep pressure therapy (DPT) is a type of therapy involving the application of controlled and profound pressure, evenly distributed across most of the external body, with the intention of inducing a calming effect while reducing uncontrolled physical activities stemming from

anxiety. DPT is widely utilized for children with autism spectrum disorder (ASD) as it is believed to alleviate stress and anxiety, as well as enhance school performance.⁴ Dr. Grandin, a renowned animal behavior scientist, implemented deep pressure therapy in her invention known as the Squeeze Machine in 1992. This machine applies deep pressure on both sides of the body, exerting external pressure inward from the head to the feet. This full-body pressure leads to relaxation and contributes to a sense of calmness and relaxation.⁵

Vibration therapy, an alternative treatment, has gained popularity in recent times. Particularly, vibrotactile stimulation employing low-frequency vibrations has found applications in therapeutic practices, yielding various therapeutic effects contingent on vibration frequency and its precise location within the body. Research conducted using vibration therapy products has generated affirmative outcomes, offering a potential means for health preservation and enhancing overall well-being.⁶ Numerous studies have provided evidence of its effectiveness in diverse areas, such as enhancing sleep quality, promoting

both physical and emotional relaxation, alleviating stress and anxiety, reducing rigidity and tremors in individuals with Parkinson's disease, and facilitating pain management in various contexts, to highlight a few.^{7,8} The design of the vibration therapy device has been carried out by Morrison, where collaboration was established with an experienced kinesiologist trained in neurophysiology to determine the placement and pattern of vibration motors on the vibrotactile stimulation to optimize the calming effect in the vibration therapy device by identifying responsive points and zones on the torso.⁹

The design of a deep pressure therapy device using vibrotactile stimulation has been carried out by Biswas. In this design, a sleeping bag is equipped with a vibration motor controlled by a microcontroller, with the goal of assisting children in achieving a more restful sleep by providing the effects of deep pressure therapy. However, this design overlooks the placement and pattern of the vibration motors, which are essential factors for optimizing the calming effect of the device.¹⁰

Based on the rationale above, the aim of this research is to create a weighted vest that provide a deep pressure effect and featuring vibrotactile stimulation based on a microcontroller. This design will consider the optimal placement and pattern of vibration motors inspired by Morrison's work in vibration therapy to maximize the calming effect.¹¹ Ultimately, the goal is to assist individuals with high stress levels using this deep pressure weighted vest with vibrotactile stimulation.

The weighted vest used in this study is the Harkla[®] (Elizabeth, North Carolina, US) Weighted Compression Vest. The Harkla[®] Weighted Compression Vest is designed with a specific focus on deep pressure therapy. Additionally, its portability allows for easy and convenient use in various settings, making it adaptable to different environments. The choice of materials in the Harkla[®] vest also plays a crucial role in ensuring comfort and effectiveness, offering a pleasant experience for the wearer, which is vital in deep pressure therapy.

MATERIAL AND METHODS

Vibrotactile Stimulation Concept

The creation of vibrotactile stimulation patterns in this study is influenced by the work of Morrison, particularly in terms of the strategic placement and pattern development for vibration motors based on responsive points and zones of the body. Morrison's research categorized patterns into five distinct types: (1) Calming and/or Feel Good (Back and Waist); (2) Feel Good (Waist); (3) Activating (Front and Back); (4) Navigation (whole body); and (5) Warning (Mid front). For our purposes, we have focused on the first category, "Calming and Feel Good", and developed four specific vibration patterns: up, down, waist left to right (WLTR), and waist front to back (WFTB).¹¹ The optimal vibration frequency for inducing a relaxing sensation is 28 Hz.¹² The positioning of vibration motors on the weighted vest, guided by responsive points and zones of the body, can be observed in Figure 1. Detailed structural information on the calming and feel-good vibration patterns is provided in Table 1.

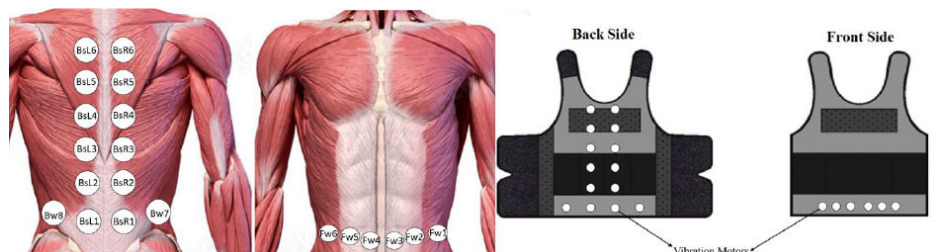


Figure 1. Vibration motors location on weighted vest according to responsive points and zones of the body.

Table 1. Patterns of vibration motors that are optimized for inducing a calming effect and feel-good

Step	Pattern			
	Up	Down	WLTR	WFTB
1	BsL1, BsR1	BsL6, BsR6	Fw1, Bw8	Fw3, Fw4
2	BsL2, BsR2	BsL5, BsR5	Fw2, BsL1	Fw2, Fw5
3	BsL3, BsR3	BsL4, BsR4	Fw3, BsL1	Fw1, Fw6
4	BsL4, BsR4	BsL3, BsR3	Fw4, BsR1	Bw7, Bw8
5	BsL5, BsR5	BsL2, BsR2	Fw5, BsR1	BsR1, BsL1
6	BsL6, BsR6	BsL1, BsR1	Fw6, Bw7	
Step Duration (ms)	350	350	600	500
Overlap (ms)	175	175	300	250

Abbreviations: WLTR, waist left to right; WFTB, waist front to back; ms, milliseconds; BsL, Back Spine Left; BsR, Back Spine Right; Fw, Front Waist; Bw, Back Waist.

Control System Design and Construction

Following the conceptualization phase, the design of vibrotactile stimulation involves the use of vibration motors operating at a frequency of 28 Hz with a rated operating voltage of 3V. The components required to control these vibration motors, aligning with the vibrotactile stimulation concept, are outlined in Table 2.

To establish control over the Arduino, the HC-05 Bluetooth module is utilized for Bluetooth serial communication between the control interface and the Arduino. The serial communication between android phone, Arduino, and electronic devices can be observed in Figure 2.

The control interface for vibrotactile stimulation has been created with the "MIT App Inventor". This interface provides the operator with the capability to establish or disconnect a Bluetooth connection and specify the duration and cycle of the selected vibration pattern. Each cycle of the vibration pattern repeats for one minute. A visual representation of the control interface for vibrotactile stimulation is depicted in Figure 3.

Table 2. List of hardware components

Component	Specification
Vibration motor	3V DC
Resistor	4.7 kOhm
Transistor	2n222
Microcontroller	Arduino Mega
Transceiver module	HC-05 Bluetooth Module
AC adapter	12 VDC 2 A
DC Voltage Regulator	LM2596

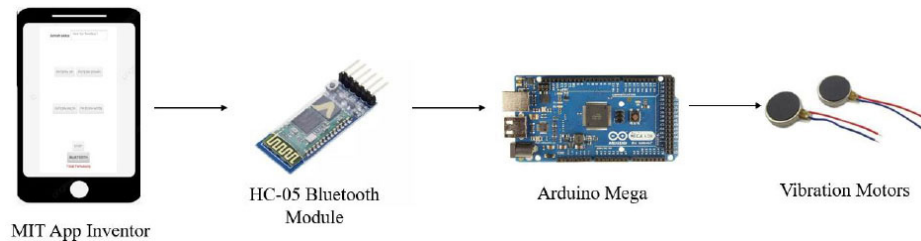


Figure 2. The serial communication of the control system.

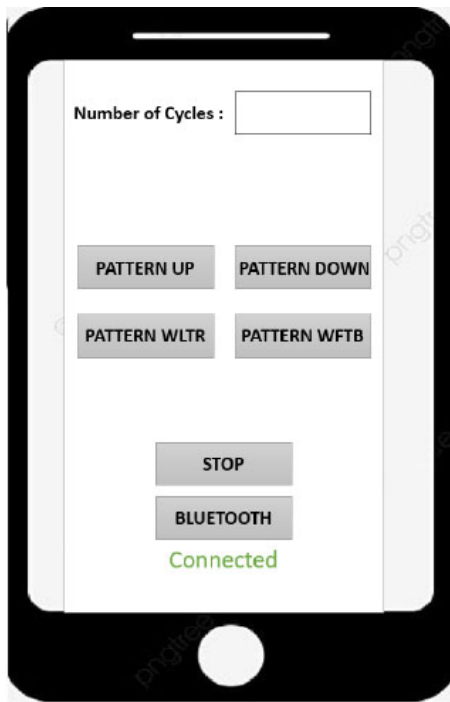


Figure 3. Vibrotactile stimulation control interface.

The assembly of components in Table 1 follows the concept of vibrotactile stimulation, and to facilitate serial Bluetooth communication between an Android phone and Arduino Mega, a wiring diagram can be depicted. You can view this wiring diagram in Figure 4.

Design Validation

Human Subject and Rating

The weighted vest with vibrotactile stimulation was tested on 10 male

student volunteers who had no history related to ASD, aged between 19-25 years, and weighing between 48-73 kg. They subjectively assessed the impact of using the weighted vest with vibrotactile stimulation in reducing stress or anxiety using the Comfort Rating Scale (CRS).¹³ The CRS was a commonly used tool that required users to evaluate what they felt on a scale from 1 to 10 (1 to 3 is Strongly disagree, 4 to 6 is mildly disagree, 7 to 9 is agree, and 10 is Strongly Agree).

In this study, the CRS was employed after the participants wore the weighted vest. The CRS consisted of six comfort term groups used to create six scales assessing different elements of comfort. The design of the Comfort Rating Scale (CRS) was based on NASA-TLX, which is a validated tool for measuring mental workload.¹⁴ The six term groups listed in Table 3.

Testing and procedure analysis

Before the testing, participants were briefly introduced to the weighted vest with vibrotactile stimulation. Each participant was assessed using four different vibration patterns (up, down, WLTR, and WFTB) on different days to ensure a fair evaluation.¹⁵ The amount of weight provided in the weighted vest corresponded to 8% of the individual's body weight, in accordance with recommendations from occupational therapists.¹⁶ Each treatment session lasted for 3 minutes for each vibration pattern.¹⁷ Following the treatment, participants completed a comfort rating test consisting

of six term groups (Emotion, Attachment, Hazard, Feeling Alteration, Movement, and Anxiety).¹⁸

RESULT

Design and Construction Result

The outcomes of the design and construction process for the Weighted Vest with Vibrotactile Stimulation are depicted in Figure 5. The weighted vest employed in this configuration is a medium-sized Harkla® weighted vest. The control box responsible for managing the vibrotactile stimulation weighs approximately 254 grams.

The weighted vest is crafted from soft, elastic neoprene, designed to provide deep pressure evenly across the vest. It features Velcro straps on the shoulders and sides to customize the fit to the wearer's body, ensuring maximal deep pressure effect. Mesh ventilation on the front, back, and sides enhances breathability and maintains airflow, keeping the user cool and comfortable.

Inside the vest, there are weighted pockets, with two half-pound weights in the front and four quarter-pound weights in the back. These weights can be adjusted according to the user's body weight, as suggested by Hung-Yu Lin.¹⁹

The vibrotactile stimulation system design for the deep pressure weighted vest is microcontroller-based, allowing users to control the device remotely using a mobile application. Users can easily adjust the vest to their size by tightening the Velcro straps on the sides and top until comfortable. The wireless vibration system can be controlled through an app installed on a smartphone. Commands sent via the phone are received by the Arduino Mega microcontroller and transmitted to the actuators, which consist of DC vibrating motors.

Validation Testing Result

The results of the validation tests conducted with 10 participants are illustrated in a bar chart. These results represent the average subjective ratings of participants for each vibration pattern and each term. The term "motion" has a negative connotation, "harm" has a negative connotation, "perceived change" has a negative connotation, "movement" has a negative connotation, "attachment"

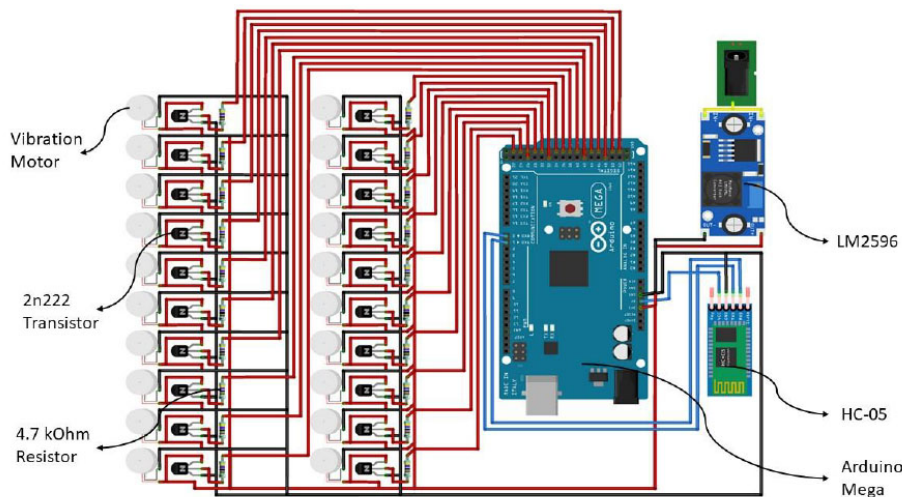


Figure 4. Wiring Diagram of Vibrotactile Stimulation.

Table 3. The six terms of the comfort rating scale

Title	Description
Emotion	I felt tense or anxious when I used this device.
Attachment	I could feel this device on my body. I could feel movement/vibration on the device.
Harm	This device could be dangerous and painful when worn.
Perceived change	I didn't feel any changes after using this device.
Movement	This device affected my mobility and restricted my freedom of movement.
Anxiety	I felt calmer when using this device.



Figure 5. Design and Construction Result.

has a positive connotation, and “calming” has a positive connotation. The subjective assessments based on the Comfort Rating Test are visually depicted in Figure 6.

Based on the results of the subjective validation testing mentioned above, participants assessed that the weighted vest with vibrotactile stimulation was safe and comfortable to use. This evaluation

was based on the “harm” and “movement” terms. Additionally, participants reported feeling a change after using the device, as indicated by the “perceived change” term. Participants also acknowledged the vibrations provided, as indicated by the “attachment” term. Furthermore, they experienced heightened calmness after using the device, as supported by

the overall ratings of the “calming” term. Notably, the “calming” evaluations for each vibration pattern were consistent, with the “down” pattern receiving the highest ratings.

DISCUSSION

Deep Pressure Therapy (DPT) is transmitted through the ascending/sensory dorsal column, and subsequently, information is relayed from cortical regions to the periphery via the descending/motor tracts. Therapeutic DPT interventions modulate physiological and psychological states through proprioceptive stimuli originating from the central nervous system, effectively calming individuals. Proprioceptive deep pressure provided through compression therapy is said to elevate the production of neurotransmitters (serotonin and dopamine), delivering soothing stimuli to the central nervous system. DPT aids in increasing activity in the parasympathetic division of the Autonomic Nervous System and decreasing activity in the sympathetic division.²⁰ The sympathetic nervous system, known for the “fight or flight” response, functions to accelerate heart rate and elevate blood pressure. The parasympathetic division, recognized as the rest and digest system, works, among other things, to decelerate heart rate and enhance glandular activity. By mitigating the flight response and activating a state of rest, anxiety can be alleviated, leading to a calmer state for individuals.²¹

To objectively measure the influence of the vibrations experienced by users in providing a calming effect, it is essential to conduct tests using physiological sensors such as Galvanic Skin Response (GSR), Electroencephalography (EEG), or heart rate sensors. These physiological sensors can provide valuable data on the user's physical responses, helping to validate the effectiveness of the calming effect delivered by the device.²²

To determine the exact amount of touch pressure received during each pattern of vibration, further research involving touch pressure sensors is necessary. This is crucial as touch pressure plays a significant role in providing a calming effect in deep pressure therapy.²³

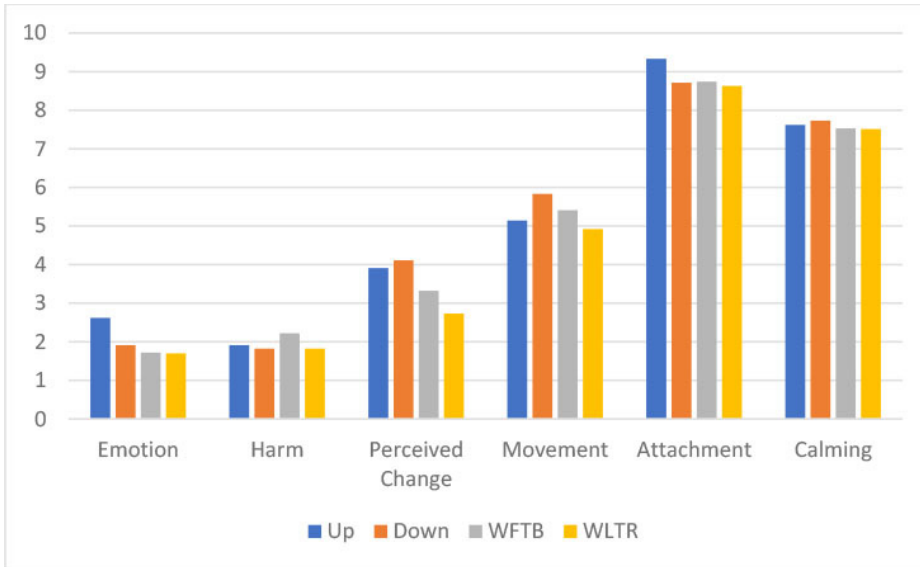


Figure 6. Graph of the Validation Testing Result.

It's important to note that this device design still has some limitations, similar to those of the sleeping bag designed by Biswas, specifically that the vibration frequency cannot be adjusted and remains fixed at 28 Hz.¹⁰ Furthermore, although this device is smaller than some other deep pressure therapy devices^{24,25}, it is not yet fully portable due to its reliance on a power supply that uses an adapter, requiring access to an electrical outlet for operation. Based on these limitations, future iterations of this research should focus on conducting tests using physiological sensors to ascertain the effectiveness of the weighted vest with vibrotactile stimulation in providing a calming effect. Additionally, modifications should be made to the device, such as replacing the power supply with a rechargeable battery, making the device more portable, and enabling control over the vibration frequency to determine the most optimal frequency for providing a calming effect.

The positive feedback from participants regarding the calming effect suggests the potential value of this innovative approach. It opens up opportunities for further exploration into the integration of physiological sensors to provide objective data on the effectiveness of the device in the future. This research has highlighted the significance of designing interventions that cater to the unique needs of individuals seeking deep pressure therapy with added vibrotactile stimulation.

CONCLUSION

In conclusion, this research contributes to the field by combining the principles of deep pressure therapy and vibration therapy while taking into account the specific placement and patterns of vibrations based on Morrison's studies. Overall, this research lays the foundation for future iterations that may incorporate advanced features and address certain limitations, such as customizing vibration frequencies and enhancing portability, to optimize the overall effectiveness of this combined therapy approach.

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CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

AUTHOR CONTRIBUTION

All authors listed have significantly contributed to the development and the writing of this article.

ETHICAL APPROVAL

Not applicable.

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INFORMED CONSENT STATEMENT

Not applicable.

DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the corresponding author.

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