A novel protocol for tactile function assessment using extended JVP domes

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Abstract

Touch is a crucial sense for perceiving the spatial characteristics of objects. The JVP dome was developed to evaluate tactile spatial acuity using a grating orientation task. The application of the traditional JVP dome to assess tactile function was limited by the ceiling effect, excessive transition gap between grating widths causing inaccurate tactile discrimination threshold measurement, and predictive bias due to the common execution protocol using grating widths in sequence. In this study, we included additional grating domes and proposed a modified examining protocol for estimating tactile discrimination thresholds to improve the accuracy of tactile function assessment. Twelve healthy participants were enrolled in this experiment. Extended JVP domes with 11 different groove widths were designed. Tactile discrimination thresholds were estimated using a modified two-down-one-up staircase method. The experiment comprised practice, training, and testing sessions, conducted by trained examiners who performed grating stimulation on participants’ index fingerpads. All participants passed the required accuracy in the practice and training sessions. Eight transition points were obtained in the testing session for each participant, and tactile discrimination thresholds were all within the width range of the extended JVP domes. The mean tactile discrimination threshold was 2.09 ± 0.84 mm. The results demonstrated that the proposed modified JVP dome set and protocol were successfully applied to assess tactile function and improved the precision of threshold measurements, avoided the ceiling effect found in traditional JVP dome, and eliminated predictive bias.

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Running title: Extended JVP domes for tactile function assessment

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Abstract

Touch is a crucial sense for perceiving the spatial characteristics of objects. The JVP dome was developed to evaluate tactile spatial acuity using a grating orientation task. The application of the traditional JVP dome to assess tactile function was limited by the ceiling effect, excessive transition gap between grating widths causing inaccurate tactile discrimination threshold measurement, and predictive bias due to the common execution protocol using grating widths in sequence. In this study, we included additional grating domes and proposed a modified examining protocol for estimating tactile discrimination thresholds to improve the accuracy of tactile function assessment.

Twelve healthy participants were enrolled in this experiment. Extended JVP domes with 11 different groove widths were designed. Tactile discrimination thresholds were estimated using a modified two-down-one-up staircase method. The experiment comprised practice, training, and testing sessions, conducted by trained examiners who performed grating stimulation on participants index fingerpads.

All participants passed the required accuracy in the practice and training sessions. Eight transition points were obtained in the testing session for each participant, and tactile discrimination thresholds were all within the width range of the extended JVP domes. The mean tactile discrimination threshold was 2.09 ± 0.84 mm. The results demonstrated that the proposed modified JVP dome set and protocol were successfully applied to assess tactile discrimination thresholds.

The modified protocol with extended JVP domes provided an effective assessment of tactile function and improved the precision of threshold measurements, avoided the ceiling effect found in traditional JVP dome, and eliminated predictive bias.

Keywords: tactile function; JVP dome; grating orientation task; staircase method; tactile discrimination
Introduction

Touch is a crucial sense for perceiving the spatial characteristics of objects. The traditional measurement of a two-point discrimination threshold has been widely employed for assessing tactile spatial acuity. However, a major drawback of this method is its inability to control the influence of non-spatial cues (Johnson & Phillips, 1981; Tong, Mao, & Goldreich, 2013). In response to this limitation, a novel measurement was developed to assess tactile spatial sensitivity using grating domes — the JVP dome. The JVP dome was introduced by Johnson, Van Boven, and Phillips in 1981 to assess grating orientation discrimination capacity (Johnson & Phillips, 1981). JVP domes have different grating widths that present different challenges to spatial processing. The JVP dome is used to evaluate an individual’s ability to identify the orientation of grating presented to the skin in a two-alternative forced-choice design, providing a more consistent and reliable measurement to quantify human tactile capacity for spatial resolution (Van Boven & Johnson, 1994a).

Since the JVP dome was introduced, the need for normative data has been raised. Studies of the grating orientation task have demonstrated that tactile thresholds differ among body parts and decline from the index to the middle finger and from the middle to the ring finger, but do not differ between the right and left hands (Craig & Lyle, 2001; Sathian & Zangaladze, 1996; Van Boven & Johnson, 1994a; Vega-Bermudez & Johnson, 2001). Furthermore, spatial discrimination, especially at the fingerpad, markedly declines as age increases (Stevens & Choo, 1996; Stevens & Patterson, 1995; Wohlert, 1996). Researchers have not only used the JVP dome to characterize tactile function in healthy individuals, but also in individuals with diseases. For example, performance in grating orientation discrimination corresponded consistently to disease progression in patients with peripheral nerve injury (Van Boven & Johnson, 1994b) and was thus considered a valid and precise measurement for evaluating sensory function after nerve repair (Klein et al., 2016). The grating orientation task is regarded as a standard method for assessing tactile acuity.

Although the JVP dome has been applied in various somatosensory studies, the grating orientation task has several limitations. First, the commercially available JVP dome set (JVP Domes, Stoelting, Wood Dale, Illinois, United States) gives rise to a ceiling effect because its greatest gap width (3 mm) does not cover the discrimination threshold range suitable for older adults and patients with neurological deficits. Second, discrimination performance falls considerably in the abrupt transition from the 3-mm to the 2-mm dome, limiting the precision of estimation of spatial discrimination thresholds (Remblay, Backman, Cuenco, Vant, & Wassef, 2000; Tremblay, Wong, Sanderson, & Cote, 2003). Third, the determination of tactile discrimination thresholds in several studies has been performed using grating widths in sequence (Craig & Lyle, 2001; Van Boven, Hamilton, Kauffman, Keenan, & Pascual-Leone, 2000; Van Boven & Johnson, 1994b); thus bias may have been present because participants may have predicted the following grating width during testing. The staircase method should thus be used to avoid predictive bias (Etter, Breen, Alcala, Ziegler, & Hayes, 2020; Etter, Miller, & Ballard, 2017; Libouton, Barbier, Plaghki, & Thonnard, 2010; Mani et al., 2022; Tracey, Greene, & Doty, 2012).

In this study, we developed a protocol to improve the precision of the tactile discrimination threshold by including additional JVP domes and establishing a procedure using a modified two-down-one-up staircase method (Levitt, 1971). We hypothesized that this protocol would yield accurate quantifications of tactile function.

Materials and Methods

Participants

Twelve healthy adult participants (six men and six women, aged between 40 and 65 years) were recruited. All participants reported normal tactile sensation and denied systemic or neurological diseases. Normal cognitive function was confirmed using JOMAC (judgement, orientation, memory, abstract thinking, and calculation) scores, and written informed consent was obtained from participants. The exclusion criteria were: (1) sensory impairment (anesthesia or hypoesthesia) or sensation change (paresthesia or hyperesthesia) in testing hand; (2) a lesion in peripheral or central nervous systems in testing hand; (3) alcoholism or history of alcoholism; (4) rheumatoid disease; (5) complex regional pain syndrome; (6) hypothyroidism;
(7) fibromyalgia; (8) end-stage renal disease; and (9) inability to follow the experiment’s instructions. The study protocol and procedure were approved by the Institutional Review Board of the Chang Gung Medical Foundation (IRB No.: 202001628B0A3). All methods were performed according to the regulations of the Human Subjects Research Act in Taiwan and the Declaration of Helsinki (1975). The study and procedure details were explained clearly to participants.

Examiner training

The examiners were trained before performing the experiment. The indentation time for JVP dome application to skin was standardized to 1 s. The experimenters practiced this action hundreds of times using a timer to ensure that the entire procedure could be undertaken with approximately equal indentation times.

Experimental setup

Extended JVP domes

The extended JVP domes comprised 11 domes with different groove widths (5, 4, 3, 2.5, 2, 1.5, 1.25, 1, 0.75, 0.5, and 0.35 mm). The diameter of each dome was 20 mm and each had a circular, convex grating surface. The domes, with equidistant grooves and bars, were mounted on a cylindrical handle. The 5-, 4-, and 2.5-mm domes were the novel domes in our study.

Experimental environment and instructions for the two-alternative forced-choice test of tactile orientation

The experimental environment setup is shown in Figure 1A. A cardboard box (30 × 22 × 15 cm) with a square opening (11 × 7 cm) for placing the testing hand and to block the view of the stimulus was set in front of the participant. A platform with Velcro was placed inside the box for fixation of the testing hand. The testing hand was fixed to the platform palm-side up at the proximal phalanx of the thumb and middle phalanx of the index finger using Velcro. An answer card was placed on the side of the non-testing hand, printed with two illustrations depicting vertical and horizontal schematics on the left and right sides, respectively.

Tactile stimulation was performed by an examiner. Each single stimulus was presented once on the participant’s index fingerpad for approximately 1 s. The sequence of tactile stimulation was randomly assigned using balanced orientations. A two-alternative forced-choice test was applied in which the participant reported perceived orientation for each stimulation. The participant did so using the non-testing hand to point to either the vertical or horizontal illustration on the answer card. If vertical orientation was perceived, the participant placed the non-testing hand on the vertical illustration side of the answer card, and vice versa (Figure 1B). Answers were recorded digitally by the examiner. In the answer record tables, vertical and horizontal orientations were denoted as “1” and “2”, respectively (Figure 2).

Experimental procedure

The experiment comprised practice, training, and testing sessions, with a 5-minute break between training and testing sessions, lasting approximately 15–20 minutes in total (Figure 3).

Before each session began, we explained the rules of the task and instructed the participants to place their testing hands palm-side up and their non-testing hands on the answer card.

Practice session

a. First, practice was conducted without the use of the cardboard box for the participants to observe the orientation of the JVP dome during stimulation. After each stimulation on the fingerpad, the participants reported the answer. This practice session concluded after three consecutive correct answers. b. Second, practice was conducted using the cardboard box placed over participants’ hands to block their view during stimulation (Figure 1A). Before each stimulation, the orientation of the JVP dome was observed by the participants. This practice session concluded after three consecutive correct answers.
Training session

a. For the training session, the setup used was the same as that in step b of the practice session (Figure 1A), except that the participants could not first observe the orientation of the JVP dome. Stimulation was conducted with grating widths from 4 to 1.25 mm and then in reverse with grating widths from 1.5 to 4 mm. Stimulation with each dome was conducted 10 times before advancing to the next. A total of 110 trials was conducted. b. After the training process, 20 trials using the 4-mm dome were conducted to evaluate whether the participants were well-trained. If the discrimination accuracy was higher than 75%, the participants were considered to have successfully completed the training session. If the discrimination accuracy was below 75%, participants completed 20 trials using the 5-mm dome. If discrimination accuracy using the 5-mm dome was higher than 75%, the participants were considered to have successfully completed the training session. If discrimination accuracy remained below 75%, the task was ended and the tactile discrimination threshold of the participant was recorded as 5 mm.

Testing session

a. In the testing session, stimulation was conducted using a modified two-down-one-up staircase method starting with the 4-mm dome. Namely, if the participant gave two consecutive correct answers, the next lowest grating width would be used; if the participant gave one incorrect answer, the next greatest grating width would be used (Figure 2B). b. A transition point was identified where the stimulation changed from decreasing widths to increasing widths and vice versa. The examiner recorded these points digitally. The session was completed when eight transition points were identified.

Data analysis and statistics

The grating widths of the last six transition points were averaged, indicating the tactile discrimination threshold (Stevens & Choo, 1996; Tracey et al., 2012; Wong, Hackeman, Hurd, & Goldreich, 2011). All data were presented as mean ± standard deviation (SD).

Results

Twelve healthy participants were enrolled in this study, namely six men and six women aged 47 to 55 years. All were right hand dominant, as confirmed using the Edinburgh Handedness Inventory. Three were tested using the left hand due to carpal tunnel syndrome or previous injury in the right hand. The highest education level was junior high school for one participant, senior high school for two participants, and university for the remaining participants (Table 1). All participants completed the task without any adverse events occurring.

First, we examined whether the participants correctly understood our instructions. All participants fully understood the instructions and correctly determined the orientations of the stimulation they received in the practice session (Table 2), indicating the use of clear instructions.

Second, we verified the feasibility of the training session protocol by examining whether participants could complete the session with the required accuracy. The results showed that 11 of the 12 participants exhibited an accuracy of greater than 75% in 20 trials using the 4-mm dome, and participant #2 exhibited an accuracy of greater than 75% in 20 trials using the 5-mm dome (Figure 4A). All participants completed the training session in 20 trials using either the 4-mm or the 5-mm dome, indicating that the training protocol adequately allowed participants to become familiar with the testing protocol.

Third, we examined the testing session protocol. We assessed whether tactile discrimination thresholds could be determined using the modified staircase method and whether the JVP domes used were adequate. Eight transition points were obtained for each participant using the testing protocol. The mean tactile discrimination threshold for the twelve participants was 2.09 ± 0.84 mm (Figure 4B). The thresholds of the twelve participants were all within the range of grating widths, indicating that, for these healthy middle-aged participants, tactile discrimination thresholds could be measured using the selected grating width range.

Discussion
This study demonstrated that, first, all participants could achieve the required accuracy in the practice and training sessions by following the instructions. Second, in the testing session, the tactile discrimination thresholds of all participants could be obtained using the modified staircase method, demonstrating the applicability of the protocol using the extended JVP domes. Third, the entire assessment was completed within 20 minutes, indicating its feasibility. Fourth, no discomfort or adverse events were reported during the experiments, indicating its safety and tolerability.

We included three additional domes with the commercial JVP domes, because these provide a limited range of grating widths and an abrupt transition between the 3-mm and 2-mm domes. The 5-, 4-, and 2.5-mm domes were chosen according to the geometric progression rule followed in the grating widths of the original set, with a common ratio ranging from 1.2 to 1.5. The tactile discrimination thresholds of two participants were above 3 mm. The use of the 5- or 4-mm domes was necessary in determining the transition points of four participants indicating the necessity of the addition of these domes. The thresholds of four participants were in the 2 to 3 mm range, indicating the need for the 2.5-mm dome to smooth this transition. The results demonstrate the superiority of the extended JVP domes as compared with the original set due to allowing a broader range of tactile function assessment.

Another major improvement is the implementation of the modified staircase method. Compared with the traditional method proposed by Johnsons et al., which is carried out in sequence by order of grating width (Johnson & Phillips, 1981), two major advantages to the proposed protocol exist. First, it reduced bias because the traditional method allows participants to anticipate subsequent grating widths in stimulation. Second, it reduced the testing duration because it involved fewer trials. The traditional method usually requires hundreds of trials, whereas the staircase method required approximately 20 to 40 trials, which can be completed within 5 minutes. This novel method thus avoids predictive bias and takes less time, making it more plausible for clinical use.

Tactile function declines with age (Stevens & Choo, 1996; Wohlert, 1996). The mean threshold of spatial acuity in adults aged 55 to 86 years is twice that in adults aged 21 to 26 (2.5 mm vs. 1.2 mm) (Manning & Tremblay, 2006). In this study, the mean tactile discrimination threshold was 2.09 mm in participants aged 47 to 55 years. The grid widths applied in this study were suitable for the discrimination thresholds of both young and older adults, indicating the benefits of our extended JVP domes.

The inter-examiner reliability of the protocol was critical. First, Bleyenheuft and Thonnard validated that variance in pressing force applied to JVP domes among examiners does not affect estimated threshold (Bleyenheuft & Thonnard, 2007). Second, although the examiners were trained before conducting the experiment, perfect orientation of the domes when presented to the fingerpad could not be guaranteed. However, because only two orientations could be indicated by participants (vertical and horizontal), we hypothesize that slight deviations in orientation did not affect the participants’ judgement of orientation. On the basis of this study’s method (Pei et al., 2014), our team is developing an automatic instrument to accurately and reliably orient the stimulus without inducing operative error or examiner fatigue.

This study has some limitations: (1) the manual presentation of the same orientation for each trial could not be ensured and (2) the findings may not be generalized to patients with advanced age, neuropathy, or stroke. Our long-term goal is to apply this novel protocol to clinical tactile function assessment, such as in screening for peripheral neuropathies, evaluating sensory recovery following nerve reconstruction, and assessing sensory impairment caused by central nervous diseases.

Conclusion

This study developed a modified protocol using extended JVP domes to assess tactile discrimination thresholds. This novel standardized method improved the precision of thresholds, was effectively applied within 20 minutes, avoided the ceiling effect encountered using traditional JVP domes, and eliminated predictive bias.

Conflict of Interest Statement
Acknowledgements

This work was supported by grants from the Chang Gung Medical Foundation (CMRPG3K1021 and CMRPG3L0661 for performing the preliminary experiments, CMRPG3M0591, CMRPG3K2152, CMRPG3L0662 and CMRPG3M0021 for manpower and data analysis, CMRPG3M0021 and BMRPJ26 for English Editing) and a grant from Taiwan’s Ministry of Science and Technology (NSC 102-2314-B-182-012 for instrument development).

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contribution

YJW, CTS, JJH, YCP, BLC designed the experiment. YJW, CTS, JJH, YCP, BLC performed the experiment. YJW, CTS, JJH, YCP, BLC analyzed the data. YJW, CTS, JJH, YCP, BLC wrote the manuscript. All authors interpreted the results of experiments. All authors edited, revised, and approved the final version of the manuscript.

References


**Tables**

**Table 1. Participant characteristics**

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#10 50 Male Right Right University
#11 52 Male Right Left * University
#12 50 Female Right Right University

+: Participants’ dominant hands were confirmed using the Edinburgh Handedness Inventory. *: The grating orientation task was completed using the left index finger due to carpal tunnel syndrome or previous injury in the right hand for these participants.

Table 2. Performance in the practice session

<table>
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<th>Participant</th>
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The numbers (1: vertical orientation, 2: horizontal orientation) in the top row indicate the orientation of stimulation and the following row depicts the answers given by the twelve participants for the corresponding stimuli. All participants correctly responded to all stimuli during practice both with and without the box.

Figures

Figure 1. Experimental setup and answer mode

(A) The participant sat in front of the examiner and maintained a palm-up position with the testing hand inserted through the square opening of the cardboard box. The proximal phalanx of the thumb and middle phalanx of the index finger were immobilized using Velcro as shown in the bottom left of the figure. The answer card was placed on the non-testing hand side. The answers were recorded by the examiner using a laptop. (B) The illustrations on the answer card by which participants reported answers corresponding to the perceived stimulation at the testing finger. If a vertical stimulus was perceived, the participants placed the non-testing hand on the side of the vertical illustration on the answer card, and vice versa.
Figure 2. Answer record tables for training and testing sessions

(A) Blank training session table. The table shows randomized numbers (1 or 2) instructing the examiner on the orientation of the stimulus. Number 1 indicated vertical stimulus and Number 2 indicated horizontal stimulus. The blank areas next to the randomized numbers were for recording corresponding answers. (B) A testing session record table showing a sample result using the modified staircase method. The stimulation started with the 4-mm dome and followed the two-down-one-up rule. For example, if the participant incorrectly responded to 2.5-mm dome stimulation once, the following stimulation would use the 3-mm dome; if the participant correctly responded to 3-mm dome stimulation twice, the following stimulation would use the 2.5-mm dome. The yellow areas denote the eight transition points.
Figure 3. Flowchart of the experimental procedure
Figure 4. Training and testing session performance

(A) Answer accuracy in the training session. The accuracy of eleven of the twelve participants was above 75% in 20 trials using the 4-mm dome. Although participant #2 exhibited only 65% accuracy in the 4-mm dome trials, she exhibited 100% accuracy in 5-mm dome trials. (B) Tactile discrimination thresholds obtained from the testing session. Data are presented as mean ± SD.

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Table 1.docx available at https://authorea.com/users/592795/articles/628112-a-novel-protocol-for-tactile-function-assessment-using-extended-jvp-domes

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Table 2.docx available at https://authorea.com/users/592795/articles/628112-a-novel-protocol-for-tactile-function-assessment-using-extended-jvp-domes
A

B

Vertical stimulus

Horizontal stimulus

Corresponding answer

Examining

Laptop

Extended JVP dome

Answer card

Cardboard box

Participant

Platform pasted with Velcro

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Accuracy
Task rule introduction

Experimental setup

Practice session

Training session

20 trials of 4 mm-dome

Is the accuracy > 75%?

No

20 trials of 5 mm-dome

Yes

Testing session

Is the accuracy > 75%?

No

End

Yes