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A Novel Temple Clamping Force Measurement Method for Eyeglasses Design

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ABSTRACT

The temple clamping force is an important factor affecting the fit and comfort of most eyeglasses. The temple height is usually very small (1.0∼6.0 mm) and the clamping force is very low (0.0∼1.0 N). However, the diameters of the effective area of available force sensors are usually larger than the temple height, and their lowest measurable force is sometimes larger than the clamping forces. This causes difficulty in measuring the clamping force using force sensors. Hence, we proposed a novel temple clamping force measurement method for eyeglasses, which only uses a digital tension meter. In this method, the displacement of the ear attachment points (EAPs) at the temple was computed based on the static and wearing expanded lateral distance of EAPs; and then the tensile force was measured based on the temple displacement by using a digital tension meter. The method has been applied to investigate the relationship between the measured clamping forces and the perceived fit scores of the temples. The experimental results are consistent with the previous report, which demonstrates the reliability of our proposed method.

Keywords: Temple clamping force measurement, Eyeglasses design

INTRODUCTION

Eyeglasses are an important tool for improving vision, increasing facial attractiveness, enhancing visual function, or conveying information. The global prevalence of myopia is growing alarmingly, especially in East Asia (Foster et al., 2014), which has led to an increase in the number of myopic glasses. There is a rapid growth in the field of augmented reality (AR) in recent years (Danielsson et al., 2020), which also has led to an increase in the number of AR glasses. Regardless of mass customization and personalization of eyeglasses, the high perceived comfort level is one important objective.

In essential, the temples are the commonly used components for eyeglasses (e.g. eyeglasses for myopia, hyperopia, or astigmatism, sunglasses, AR glasses), and the clamping force at the temple region can significantly affect the comfort perceptions for the eyeglasses (Zhang & Luximon, 2017). Too much clamping force may cause pain in the ear attachment area of the wearer. On another hand, too little clapping force may not provide enough friction at the

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temples to prevent the glasses from sliding. Hence, confirming the comfortable clamping force of the temples for the users is significant. Moreover, it is the foundation to measure the clamping force of the temples.

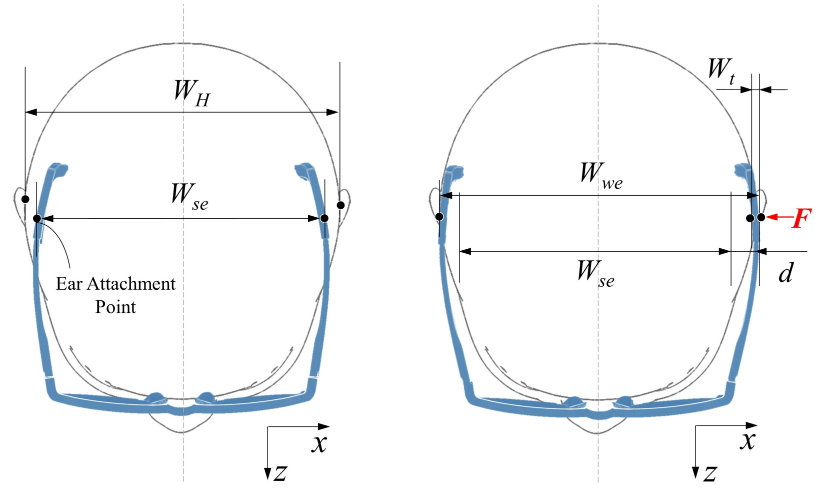
In previous studies, the clamping force of the temple is usually measured by using various strain gauges as a control or independent variable in experiments. Du et al. (2022) placed a strain gauge (FlexiForce® A201 1 lb, Tekscan Inc., USA; accuracy of 1/4 ±3%) on the head contact area of the prototype's right temple to measure its clamping force as a control variable. Instead of measuring the clamping force directly on the temporal regions of the head, Kouchi et al. (2004) pasted a strain gauge (Kyowa Electronic Instruments Co. Ltd., KFG-2-120-C1-11) on the medial (lateral) side of the eyeglasses' temple. Similarly, Mashima et al. (2011) attached a strain gauge (Kyowa) on the temple arm of the wearing eyeglasses and measured the voltage as the clamping force; their objective is to investigate the relationship between the clamping force (an independent variable) and wearing comfort around ears.

In this study, instead of using strain gauges, we developed a novel device based on a digital tension meter to measure the clamping force at the temples indirectly. We calculated the displacement of the temple contact points based on their lateral distances under static and wearing conditions, and then measured the tensile force to increase the lateral distance of two temple contact points (under static condition) by the same displacement. Since there is always an equal and opposite force for each force, this tensile force is also equal to the clamping force at the temples. Furthermore, we applied this method to measure various clamping forces, investigated the quantified relationships between the objective clamping forces and subjective human perceptions, and confirmed the clamping force with the highest perceived comfort score.

METHOD

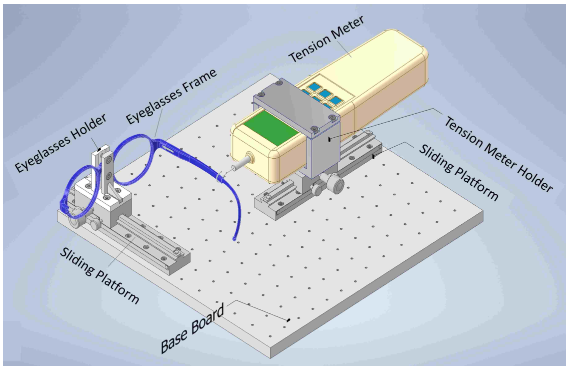
To each force, there is always an equal and opposite force. Hence, instead of the (online) clamping force, we measure the offline clamping force (tension) with the same displacement of the ear attachment points (EAPs) at the temple. In the temple clamping force measurement for each participant, the static W_{se} and wearing W_{we} expanded distances of the EAPs on the temple (see Figure 1) were measured using the digital vernier and spreading caliper, respectively. Because the eyeglasses are symmetric, the displacement d of the EAP for one temple is, $d=(W_{se} - W_{we})/2$. $W_{we}=W_t + W_H$, where W_t is the width (thickness) of the temple.

To measure the clamping force, we designed and produced a device using a digital tension meter (Model: SH-2, Shanghai Siwei Instrument Manufacturing Co., Ltd., Shanghai; resolution: 0.001; and range: 0–2 N, see Figure 2). In our experiment, with the eyeglass frame held in place, the tension meter was slid from the position with the tensile force of 0 N to a new position with a displacement d using the rotating screw. In this new position, since action and reaction forces are reciprocal (opposite) on the temple, the measured tensile force equals the corresponding clamping force when the participant wears this eyeglass frame. Because this clamping force is very small (usually

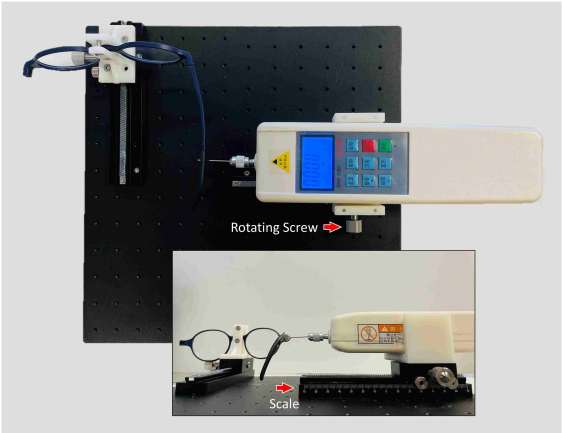


(a) (b)

Figure 1: Eyeglasses with a head model under different conditions. (a) Static condition. (b) Wearing condition. W_{se} and W_{we}: the expansion distances of the ear contact (attachment) points at the temple under static and wearing conditions correspondingly. W_H: the head width. d: displacement of the ear attachment points. W_t: the width (thickness) of the temple around the ear attachment points. F: the clamping force of one-side temple.



(a)



(b)

Figure 2: Offline temple clamping force measurement using a digital tension meter. (a) digital rendition of our measurement device. (b) actual measurement device in use.

ranging from 0.0-0.6 N) and the tension meter is very sensitive, the tensile forces were measured three times and the average was calculated as the result.

APPLICATIONS

Experiments

Because there is no valid measure of the clamping force on the wearer, it is difficult to compute the errors of the proposed method directly. Theoretically, the greater the displacement of the temples, the greater the clamping force at the temples, and the tighter the wearer perceives. Hence, we changed the temple displacement of the eyeglasses to produce different clamping forces, recruited participants to perceive their fit, and examined the relationship between the measured clamping forces and perceived fit scores. The fit of the temples was defined as the perceived ability to wear the eyeglasses properly with the clamping force at the temple region being neither too loose nor too tight.

In this experiment, 30 Chinese children (15 males and 15 females) aged 14–17 years were recruited. The independent and dependent variables are the clamping force and perceived fit scores, respectively; and the control variables are the eyeglasses weight, temple height/length, and nose pads width. For each participant, six eyeglasses prototypes with different clamping forces were tested and the fit of the temples was evaluated by using 7-point Likert scale questions (Extremely loose, loose, slightly loose, perfect fit, slightly tight, tight, and extremely tight). Moreover, each prototype was evaluated under static conditions, where each participant was asked to sit calmly without engaging in any strenuous body movements, which represented conditions experienced during work or study. Hence, each participant had six prototypes and seven tests (including one repetitive test). There was a one-minute break between tests.

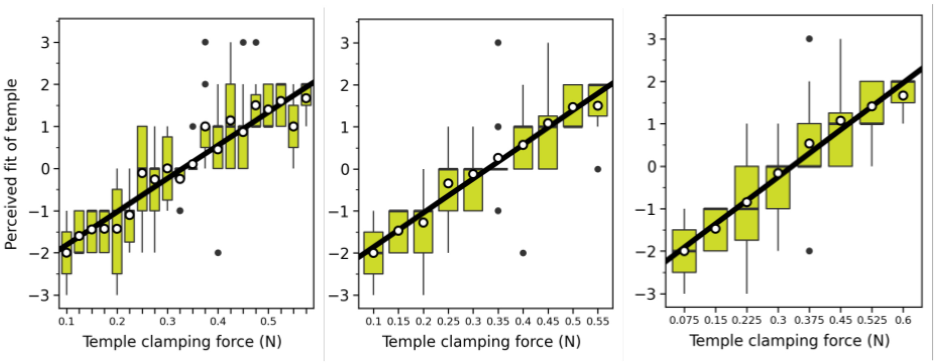
Since discrete data can increase the representation of knowledge behind the original data and help knowledge retrieval methods to produce better results (Fu, 2011; Chaudhari et al., 2014), a data discretization method was used to transform the clamping forces from continuous data F into discrete data $\ddot{F}$ by using an interval t_f: $\ddot{F} = \text{Round}(F / t_f) \times t_f$, where Round($\cdot$) is a rounding function. Ordinary least squares (OLS) regression (Montgomery et al., 2021; Freund et al., 2006) was performed to compute trendlines to quantify the relationships between the measured clamping forces and perceived fit scores for the temples.

RESULTS

To confirm the reliability of the perceived fit scores of the temples, the collected repeated data were used to calculate the intraclass correlation coefficient (0.75). This indicates the good reliability of our collected data (McGraw & Wong, 1996). **Table 1** and **Figure 3** show the quantitative and qualitative mathematical modeling results of perceived fit scores of the temples using OLS regression with different force intervals, respectively. Different force intervals can lead to a different number of observations, thereby producing different trendlines. The R-squared (R^2) values for different trendlines are

Table 1. Mathematical modeling results of perceived fit scores for the temples using OLS regression with different force intervals.

Force Intervals t_f	No. Observations	Trendlines	R-squared	Adj. R-squared
0.025	20	y=7.87x−2.60	0.936	0.932
0.050	10	y=7.03x−2.40	0.915	0.905
0.075	8	y=7.39x−2.47	0.983	0.981



(a) (b) (c)

Figure 3: Fitted trendlines with original data distributions of temple's perceived fit scores by using different intervals t_f in data discretization. (a) $t_f = 0.025$. (b) $t_f = 0.050$. (c) $t_f = 0.075$. The green boxplots indicate the perceived fit score distributions under the specific temple clamping force, the white scatters indicate the mean perceived fit scores, and the black lines indicate the fitted linear trendlines. Note that there is a linear relationship between the measured clamping forces and perceived fit scores, which is not affected by the intervals in data discretization.

more than 0.9, which indicates a strong relationship between the independent and dependent variables. The coefficients of the three trendlines (see **Table 1**) are similar and the qualitative results (see **Figure 3**) also show these trendlines are similar, especially their slopes. This shows that there is no significant difference in the use of the three different force intervals in the data discretization to calculate the trendlines.

DISCUSSIONS

Since the temple clamping force can significantly affect the wearer's perceived comfort, measuring the temple clamping force is a basic technique for eyeglasses fit and comfort evaluation. However, there are limited studies on this important technique.

A previous report (Saadeh et al., 2017) conducted a performance comparison among several commonly used sensors and found that FSR 402 can measure the lowest force (0.423N), followed by FlexiForcer® A201 (0.522 N). The temple height is usually very small (1.0~6.0 mm) and the clamping force is also small (0.0~1.0 N). However, because of the available force sensors, their diameters of sensing area are usually larger than the temple height, and their lowest measurable force is sometimes larger than the clamping forces. These can easily lead to the inaccurate measurement of the temple clamping force on the ear regions. Furthermore, before measurement for strain gauges, the relationship between the load and the strain is needed to be calibrated by hanging a weight on the temple. However, their calibration status is usually different from their measurement status (the sensitive grid is easily deformed on the facial surface and their contact area and positions are not the same), and this discrepancy also easily decreases their measurement accuracy.

In comparison, there are three advantages of our method: (1) our method has a wider application range, which can measure the clamping forces of the temples with all current heights; and (2) our method is more convenient, which can also use the wearer's head width to measure the clamping forces and does not need a force calibration. This with the perceived comfort trendlines can be used to predict the overall comfort and assess the products for the target population. However, our method only measures the tensile force of the EAP at the temple, in which status is also different from the actual eyeglasses-wearing status for the wearer. Because there is no valid measure of the clamping force on the wearer, it is also unknown how much of a measurement error this status difference would lead to.

We applied our method to investigate the relationship between the measured clamping forces and perceived fit scores of the temples successfully. The experimental results indicate that there is a strong linear relationship between the measured clamping forces and perceived fit scores of the temples. This is consistent with previous studies on the relationship between the prototype sizes (corresponding to different pressures) of in-ear wearables and their perceived fit scores (Fu & Luximon, 2021). Hence, this application demonstrates the reliability of the proposed clamping force measurement method for eyeglasses.

CONCLUSION

In this paper, we proposed a novel temple clamping force measurement based on a digital tension meter for eyeglasses. Compared to the force sensors, this method is more convenient and has a wider application range for temples with various heights. Although there is no valid measure to provide ground-truth data to calculate the measurement accuracy of our method, we have used a temple-fit perception experiment to demonstrate its reliability. We believe that this novel method can be applied to investigate the comfortable clamping force for various eyeglasses and optimize their ergonomics design, e.g., eyeglasses for myopia, hyperopia, or astigmatism, sunglasses, and AR glasses.

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