DEW19

INTERNATIONAL CONFERENCE ON
DESIGN FOR EXPERIENCE AND WELLBEING

2019'情感体验与宜人性设计国际会议

THE 2019 INTERNATIONAL CONFERENCE ON DESIGN FOR EXPERIENCE AND WELLBEING

论 文 集

CONFERENCE PROCEEDINGS

HOST

西北工業大學
NORTHWESTERN POLYTECHNICAL UNIVERSITY

TU Delft

Heritage & Vision

Proceedings of the 2019 International Conference on Design for Experience and Wellbeing

Xi'an, September 23-25, 2019

Edited by

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Editorial

These are the proceedings of the 2019 International Conference on Design for Experience and Wellbeing, September 23-25, 2019 (DEW19) in Xi'an, China, co-organised by Delft University, the Northwestern Polytechnical University, and the Delft Institute of Positive Design.

The goal of experience design has been evolving from simply offering the users with enjoyable momentary experiences to enhancing long-term wellbeing of individuals and societies through design. At DEW19, international design scholars and practitioners exchanged state-of-the-art knowledge and insights concerning the cross-disciplinary field of experience design and its ongoing evolution towards wellbeing-centric design. The theme of the conference was "Heritage and Vision". We believe that this transition from experience design to wellbeing-centric design requires a critical review of the heritage (i.e. knowledge on experience design) that the field has accumulated over the decades, as well as a visionary reorientation, and a new level of interdisciplinary collaborations and explorations.

The proceedings provide you with an overview of the presented papers. We thank the authors for choosing to disseminate their research at this conference. In addition, we would like to thank the reviewers, copyeditors, designers, and all the other people who have been instrumental in assuring the high quality of papers published in these proceedings.

The DEW19 Program Committee

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Founding director of the Delft Institute of Positive Design (DIOPD),
Partner of the research and design agency Emotion/Studio,
Board member of the International Design & Emotion Society,
Keynote topic: It is Love, my Friend.

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Tsinghua University's first batch of senior liberal arts professors Professor of Academy of Design & Arts,
Tsinghua University, Ph.D.
Mentor Honorary Vice President and Director of Expert Committee of China Industrial Design Association
Chairman of the DDF Award committee,President of Design Strategy and Prototype Innovation Institute,
The Research Center of Arts and Science, Tsinghua University Adjunct professor and Ph.D.
Mentor at Guangdong University of Technology Part-time professor and doctoral tutor of Nanjing Arts Institute
Keynote topic: Design Methodology

Tuuli Mattelmaki (Aalto University, Finland)

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Head of Department of Design at Aalto University School of Arts Design and Architecture
The leader of ENCORE research group
Keynote topic: Reconsidering Empathic Design

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Professor, Doctoral supervisor
Science and technology progress award, National Defense Science and Technology Commission;
Shaanxi provincial science and technology advancement prize;
Chinese university science and technology progress award;
Science and technology progress award for universities and colleges, Shaanxi province;
Outstanding teaching award, Shaanxi province;
Innovation award of Chinese industry-university-research cooperation;
Baogang Extraordinary teaching award.
Keynote topic: coming soon

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Vice dean of the College of Design and Innovation at Tongji University
Leader of the development of the Interaction Design academic direction
Keynote topic: Interaction Design, Visual Analysis, Interactive Installation and Art

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The Director of Critical Alarms Lab at Delft University of Technology
The leader of the Silent ICU Project of the Erasmus University Medical Centre in Rotterdam
Keynote topic: coming soon

Santiago de Francisco(Universidad de los Andes,Colombia)

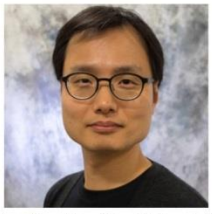
Assitant Professor,
designer and professor at the School of Design at Universidad de los Andes in Bogotá Colombia,
Keynote topic: Colombian Design in the Multiverse of Emotions and Wellbeing

Matthias Laschke (University of Siegen, Germany)

Senior research scientist, Dr.
Senior research scientist in the University of Siegen,
Keynote topic: Technology plays an important role in almost every activity.

Anna Louis Bang(Kolding School of Design,Denmark)

Associate Professor, PhD,
Director of Research & Development,
Design School Kolding Denmark,
Keynote topic: Textile design as a means for the experience of wellbeing



JungKyoon Yoon (Cornell University, USA)

Assistant Professor, PhD,
Assistant Professor in the Department of Design and Environmental Analysis at Cornell University,
Keynote topic: Why bother designing for positive emotions?

Contents

Posture Analysis and Measurement of Crew in Manned Submersible

Xu Weizhe[1, 2], Cao Jun[1, 2], Chen Zhengsheng[3]

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Abstract: There is no domestic anthropometric database of crew in manned submersible. In this paper, by collecting the p collection and data processing, body dimensions of crew in the manned submersible cabin are obtained. It provides reference for the layout design of manned submersible cabin in the future.

Keywords: manned submersible; anthropometric database; cabin; body dimension; posture analysis

1 Introduction

The manned cabin is the node of man-machine interaction of manned submersible(Chen Dengkai et al, 2018). The basic principle of the layout design of the cabin is human-centered, which means the design relies on the human dimensions. In this way, we can get a reasonable space layout and comfortable working posture, make the crew complete the task efficiently and reduce the probability of misoperation as far as possible.

Currently, there are more than 90 large-scale anthropometric databases in the world, among which European and American countries account for the majority, Asian countries account for about 10, and Japan accounts for more than half(Luo Shijian et al, 2002, Hu Huimin et al, 2011, Zhao chaoyi et al, 2011, Zhao chaoyi, 2013). The anthropometric database available for design reference in China includes *Human dimensions of Chinese adults(1988)* and *Human dimensions of Chinese male pilot population(2003)*.The above two standards include body dimensions such as standing posture, sitting posture, head, hands and feet.

Limited by factors such as depth of diving, materials of manned cabin and material processing technology, the diameter of manned submersible cabin with a depth of more than 6000m is usually less than 2.1m, but the crew usually has three members (Liu Tao et al,2012, Xu Weizhe et al,2016). In the narrow space of the manned cabin, the trunk and limbs of the crew cannot be fully stretched, and some body dimensions concerned with design cannot be obtained from the existing database. It is urgent to develop the anthropometric database of manned submersible.

2 Collection of crew posture in submersible cabin at Home and abroad

2.1 Jiaolong manned submersible

Jiaolong has a pilot seat in the center and movable passenger seats on both sides. The driver sits on the seat at rest with his upper body naturally relaxed and his legs towards the bow, leans forward close to the window when looking out. Passengers sit with their knees facing the center of manned cabin when resting, adopt the posture of holding knees or cross-legged towards the bow when observing and recording. When observing the situation outside the window, squat observation is adopted. As shown in figure 1.

Figure 1.Posture of crew in Jiaolong manned submersible

2.2 SHINKAI 6500 manned submersible

SHINKAI 6500 floor uses the form of integrated cover fabric, instead of delimiting personnel activity scope. It conforms to the Japanese tatami use habits. Crew in the cabin take the cross-legged or kneeling posture when resting, and adopt the lateral posture when working through the observation window. As shown in figure 2.

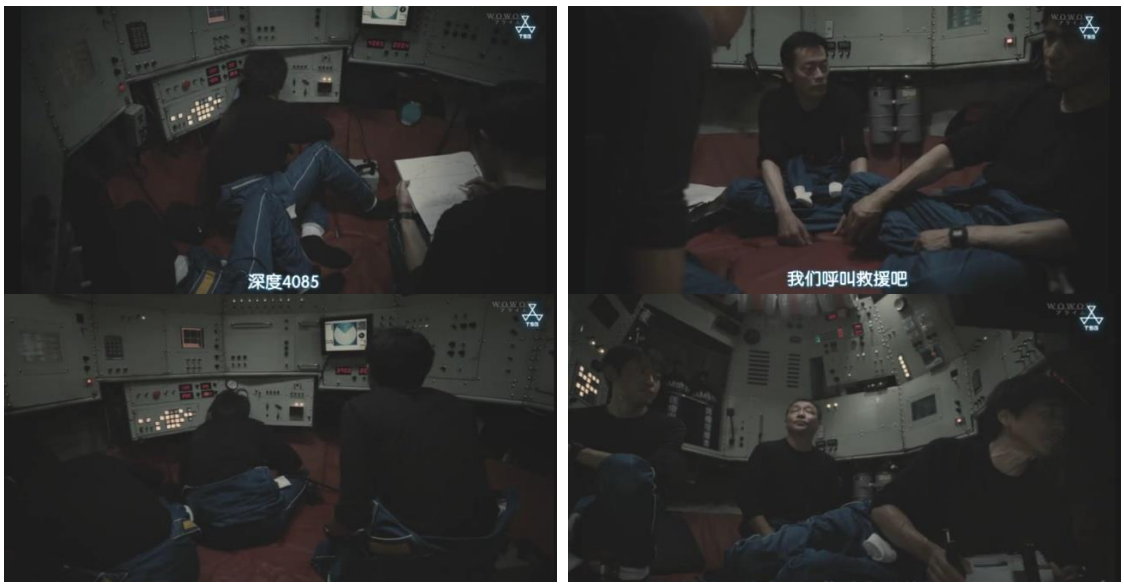

Figure 2. Posture of crew in SHINKAI 6500 manned submersible

2.3 Mir manned submersible

The driver of Mir sits in the middle of the cabin with his legs facing the bow. During the operation, he leans forward with his face close to the observation window. When resting, passengers on both sides adopt the posture of holding knees or cross-legged toward the bow. When observing the situation outside the window, they lie on their side of the work table. As shown in figure 3.

2.4 New Alvin manned submersible

The driver of the New Alvin sits in the center of the capsule, leaning forward to get a view through three viewing Windows in the front. When passengers observe the

observation Windows on both sides, they should sit at the back of the floor and curl up on the upper body for observation. When they observe the observation window on the front side, they should use side lying posture. As shown in figure 4.

Figure 3. Posture of crew in Mir manned submersible

2.5 Deepsea Challenger manned submersible

The diameter of Deepsea Challenger cabin is only 1.09m, and the lower limbs and trunk of the driver cannot move in a wide range. During the whole diving process, the operator always adopts the posture of holding knees or crossing legs. As shown in figure 5.

Figure 4. Posture of crew in New Alvin manned submersible

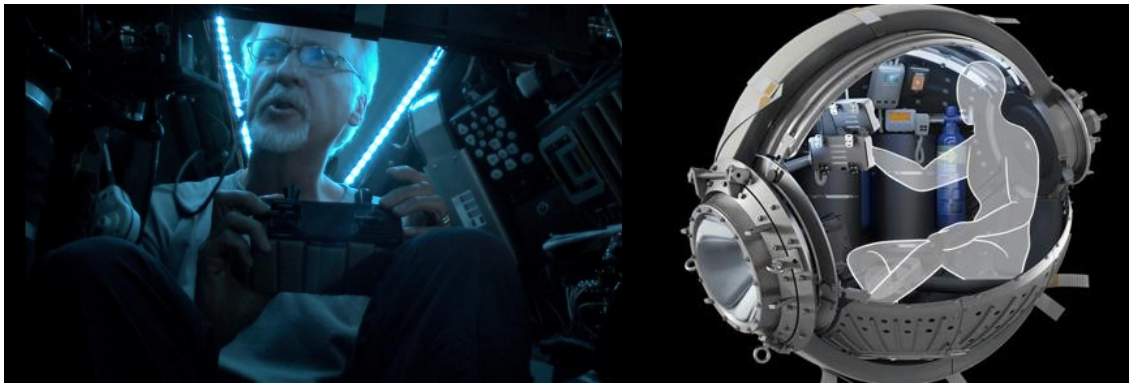

Figure 5. Posture of crew in Deepsea challenger manned submersible

3 Posture analysis of cabin crew

According to the collection of the cabin posture of submersibles at home and abroad, the sitting posture of the crew during rest or monitoring the equipment is usually relaxed sitting, cross-legged sitting and knee sitting. When looking out of the window or operating, the lower limbs should be cross-legged, and the upper body should lean forward as far as possible close to the observation window, or observing by lying on the side. When the knee-hugging posture is not enough, it can be changed to squat to observe.

JACK(Chen Dengkai et al, 2018) and Delmia (Xu Weizhe, 2013) are commonly used tools for evaluating man-machine effectiveness. In this paper, RULA(Rapid Upper Limb Assessment) module of Delmia is used. It divides the range motion of each joint of the human model, defines different colors and assigns different points. The green area represents 1 region, the red area represents 2 regions, the purple area represents 3 regions, and the black area represents 4 regions, as shown in figure 6. Calculate the comfort score of the designed posture by RULE method, and Repeatedly optimize the angles of each joint. The final designed posture is shown in figure 7.

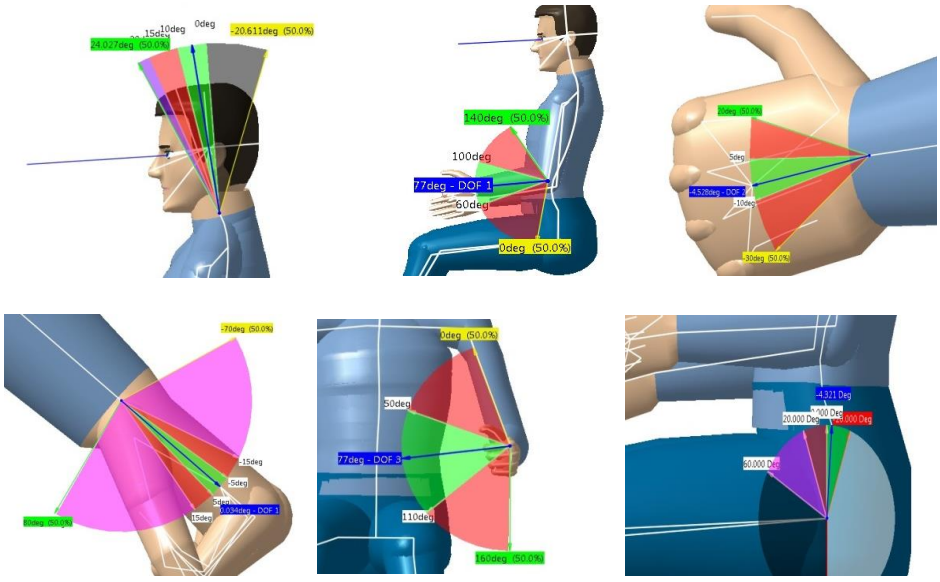

Figure 6. Schematic diagram of joint range scoring

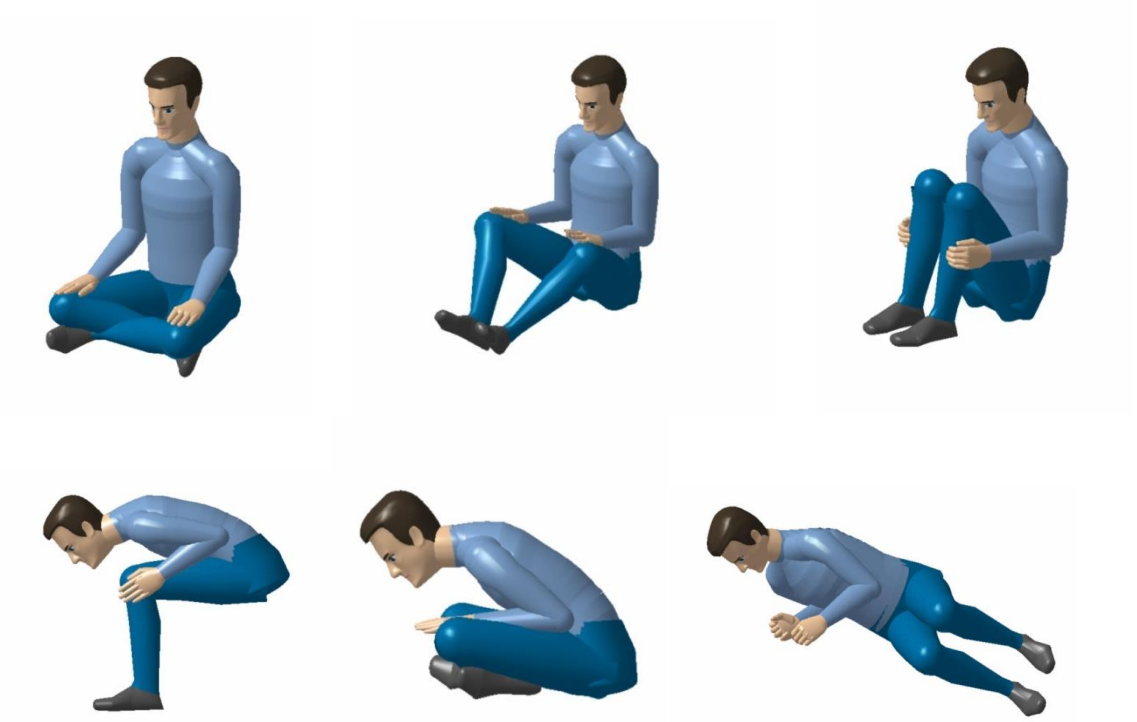

Figure 7. Designed posture

In the above posture, the upper body is slightly twisted when observed by lying on the side, and the curvature of the spine changes with the position of the actual observation window. In this posture, the distance from the eye site to the ischial nodule is between the height of the eye site of sitting upright and curled up. So do not collect relevant data.

4 Name and definition of measurement item

(1) The height of relaxing sitting posture: the lower limbs are sitting upright, the upper body is naturally relaxed. The vertical distance from the top of the head to the chair surface;

(2) The eyes height of relaxing sitting posture: the lower limbs are sitting upright, the upper body naturally relax. The vertical distance from the pupil to the surface of the chair;

(3) The Eye-Hip distance of upright sitting with maximum forward: the lower limbs are sitting upright, the upper body is stretched forward close to the thigh, the head is raised to the limit position. The horizontal distance from the pupil to the back point of the hip.

(4) The eyes height of upright sitting with maximum forward: the lower limbs are sitting upright, the upper body is stretched forward close to the thigh, the head is raised to the limit position. The vertical distance from the pupil to the surface of the chair.

(5) The eyes height of curled up posture: bend the upper body as far as possible, with the eye point on the same vertical surface as the ischial tubercle point and look forward. The vertical distance from the pupil to the surface of the chair.

(6) The sit depth of holding knees posture I:Sit with knees holding, knees bent to the limit position. The horizontal distance from toe to back point of back.

(7) The sit depth of holding knees posture II:Sit with knees holding, knees bent to the limit position. The horizontal distance from toe to back point of hip.

(8) The sit depth of cross-legged posture: cross the legs. The horizontal distance from forward point of the lower limbs to back point of hip.

(9) The sit width of cross-legged posture: cross the legs. The horizontal distance between the widest points of the lower limbs.

(10) The Eye-Hip distance of cross-legged sitting with maximum forward: cross the legs with upper body maximum forward, the head is raised to the limit position. The horizontal distance from the pupil to the back point of the hip

(11) The eyes height of cross-legged sitting with maximum forward: cross the legs with upper body maximum forward, the head is raised to the limit position. The vertical distance from the pupil to the surface of the chair.

The above human body size is related to each person's sitting habit and body flexibility, and the actual data collection needs multiple measurements to take the average. The diagram of the measurement project is shown in figure 8.

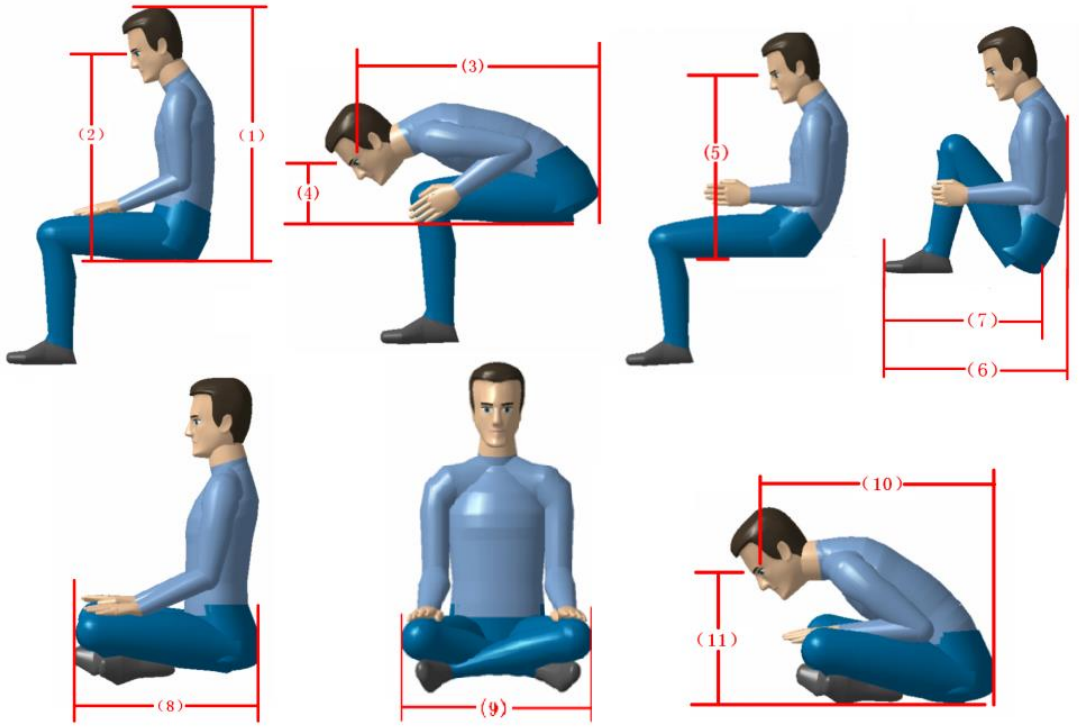

Figure 8. Diagram of measurement item

5 Data processing

Refer to *General rules of using percentiles of the body dimensions for products design(1988)*, the layout of manned cabin should be designed so that the 50th percentile of personnel is in the most appropriate position, at least the 5th to 95th percentile of personnel is easy to operate, and the 1st to 99th percentile of personnel can operate safely. Therefore, measurement data need to be processed to get the 1st, 5th, 50th, 95th and 99th percentiles of each data.

The number of samples selected for measurement in this paper is 10, and the average height of the samples (1770mm) differs greatly from that of the standard

database (1711mm), so the measured values of each item cannot be directly used for percentile calculation.

The ratio between the measured item value and the height of the measured person is denoted as X, the height data in the standard database is denoted as Y, and the (x,y) probability density is set as f(x,y), then the distribution function of the desired item value Z=X×Y is

$$F_Z(z) = \iint_{x \times y \le z} f(x,y)dxdy$$
$$= \int_{-\infty}^{\infty} \left[\int_{-\infty}^{\frac{z}{y}} f(x,y)dx \right] dy$$

Assume $x = \frac{u}{y}$, get

$$F_Z(z) = \int_{-\infty}^{\infty} \frac{1}{y} \left[\int_{-\infty}^{z} f(\frac{u}{y}, y)du \right] dy$$
$$= \int_{-\infty}^{z} \left[\int_{-\infty}^{\infty} \frac{1}{y} f(\frac{u}{y}, y)dy \right] du$$

The probability density Z is

$$f_Z(z) = \int_{-\infty}^{\infty} \frac{1}{y} f(\frac{u}{y}, y)dy$$

Suppose that the height and the ratio between the measured item value and the height of the measured person conforms to normal distribution, i.e $X \sim N(\mu_1, \sigma_1^2), Y \sim N(\mu_2, \sigma_2^2)$ .Because x and y are independent, then

$$f_Z(z) = \int_{-\infty}^{\infty} \frac{1}{y} \bullet \frac{1}{\sqrt{2\pi}\sigma_1} \bullet e^{-\frac{(\frac{z}{y}-\mu_1)^2}{2\sigma_1^2}} \bullet \frac{1}{\sqrt{2\pi}\sigma_2} e^{-\frac{(y-\mu_2)^2}{2\sigma_2^2}} dy$$

The average and standard deviation of the height can be obtained by referring to Human dimensions of Chinese male pilot population, the average and standard deviation of the ratio between the measured item value and the height of the measured person can be calculated by measured data. The probability density of requested item

value Z is doing numerical integrals by Simpson method with variable step length, and the probability is doing double numerical integrals by Simpson method with variable step length. MATLAB encapsulates the above algorithms, which are quad () and dblquad () . Each observation parameter is discretized by a fixed step, and the discrete points on both sides of the probability distribution of 1%, 5%, 50%, 95% and 99% are found. Then, the corresponding value of the probability is calculated by linear interpolation. As shown in figure 9 and table 1.

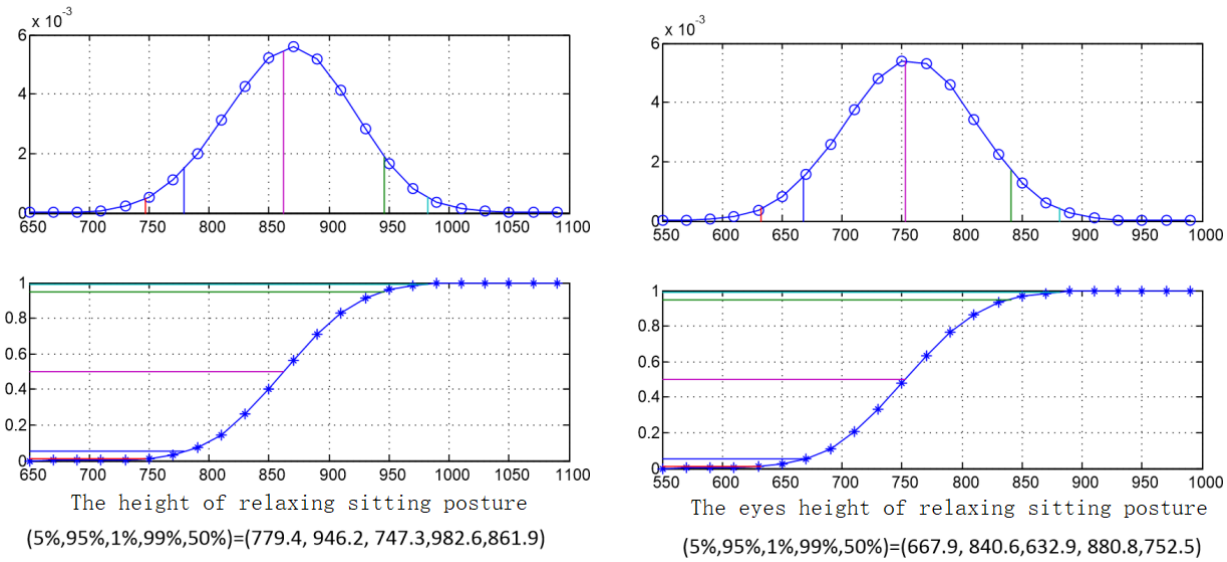

Figure 9. Diagram of data processing example

Table 1. Body dimensions of crew in the manned submersible cabin

No.	measurement item	1%	5%	50%	95%	99%
1	The height of relax sitting posture	747.3	779.4	861.9	946.2	982.6
2	The eyes height of relax sitting posture	632.9	667.9	752.5	840.6	880.8
3	The Eye-Hip distance of upright sitting with maximum forward	641.4	671.4	740.5	812.0	844.3
4	The eyes height of upright sitting with maximum forward	89.4	139.3	260.0	382.9	438.0
5	The eyes height of curled up posture	581.2	608.7	680.6	754.6	785.4

6	The sit depth of holding knees posture I	687.7	708.8	759.4	811.7	835.3
7	The sit depth of holding knees posture II	578.9	604.2	667.1	731.9	759.6
8	The sit depth of cross-legged posture	433.4	473.1	568.2	667.8	722.7
9	The sit width of cross-legged posture	550.8	573.9	631.2	689.5	716.4
10	The Eye-Hip distance of cross-legged sitting with maximum forward	466.1	509.3	612.9	721.7	783.5
11	The eyes height of cross-legged sitting with maximum forward	238.6	293.4	434.5	578.4	649.2

6 Summary

China's manned submersible design capability has been steadily improved in recent years, and more and more professional data are needed to guide research and development in the future. Throughout the development of aircraft, automobile and other industries, there are their own anthropometric databases. This paper explores the human dimensions research on the posture of crew in the cabin of manned submersible. The human body data obtained still needs to be improved. In the future, it can be expanded from the directions of sample quantity, measurement project and measured population, so as to make the data have higher credibility and wider use.

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Public Art on the London Underground and Wuhan Metro：A Comparative Study on the Art Form of the Metro Public Art Projects

Yi Liu, Feng Wang, Binglin Ren

(Jiangnan University)

Abstract: Metro public art has been developing rapidly in China in the last decade. This study attempts to deconstruct and analyze it through the dimension of the art form. In order to provide a better aesthetic and ride experience for citizens with metro public art, this paper takes the public art projects of the London Underground and Wuhan Metro as samples and makes a comparative study on the art form of their projects in the underground spaces. This research aims to figure out what can be improved and why we shall reflect it on the Wuhan Metro and to propose innovative ideas for the future development of domestic metro public art. The first part gives a brief of the metros of the two cities, then the art projects of the London underground and Wuhan metro art stations are listed and introduced. By comparing and researching their intrinsic forms and external forms via representative works, the second part of this study offers details of the metro public art projects in the two places. The article concludes with the results of comparative research and puts forward some ideas for the future development of domestic metro public art.

Keywords: Public Art; London Underground; Wuhan Metro; Art Form

In the modern urban environment of China, art projects have become an essential part of all kinds of public spaces. Art has gradually been normalized. Although public art started late in China, it is developing at a very rapid pace. In the past, compared with developed countries such as the UK and America, Chinese citizens have fewer opportunities for meeting art in their daily lives, and their aesthetic experience and foundation are relatively insufficient. In recent years, along with the fast expansion of China's subway transportation system, the planning and construction of art metro stations enable public art to enter and exist in our daily lives in a normalized way. The citizens have the opportunity to get close to the artworks and experience them. At the same time, the existence of art is playing an essential role in beautifying the public space, rising the image of the city, and improving the passenger's experience and other aspects. However, in daily situations, our large-scale and heavily invested metro public artworks seem to be lacking attraction to the passengers. Some passengers even commute in the art station every day, but they have very few impressions of the artworks in the station. Why can't these huge and well-made artworks affect their viewers further? What can be improved? This paper attempts to deconstruct and analyze these questions based on Clive Bell's art form theory. The benefit of this research is to provide a better aesthetic and ride experience for citizens through comparative study.

1. Overview of Urban Metros in London and Wuhan

The London Underground has a history of 150 years and is the oldest metro in the world. It is managed and operated by Transport for London. Eleven lines are covering the Greater London area. China's subways started relatively later than London's. In the 1960s, Beijing, Shanghai, Guangzhou and other major cities began to build subway systems. The construction of the Wuhan rail transit system began at the end of 2000 and

is currently in the process of construction acceleration. In the past 19 years, nine routes have been built, and other routes and extension projects are still in progress.

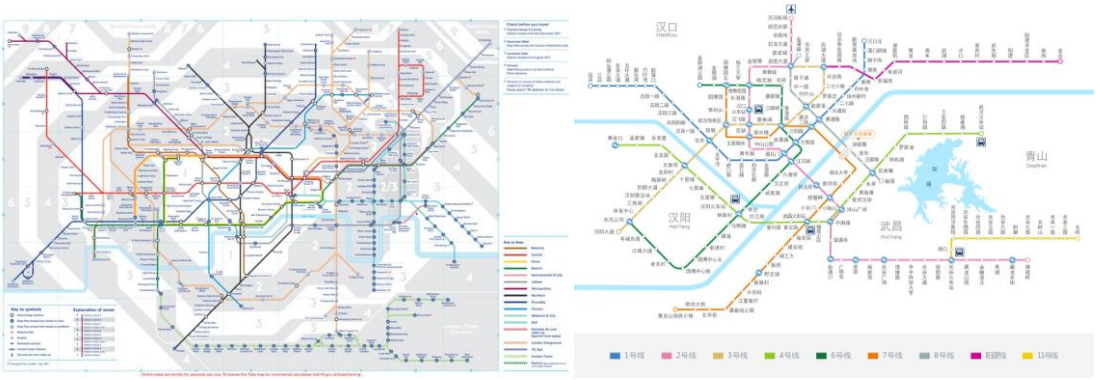

Figure 1. Maps of London Underground (Left) and Wuhan Metro (Right).

Note：Map of London Underground. Retrieved from https://tfl.gov.uk/maps/track/tube

Map of Wuhan Metro Retrieved from

http://www.wuhanrt.com/public_forward.aspx??url=public_content_page.aspx?newid=3758e97c-94fc-414d-b273-ccb942e930f8&dtag=menu_motion_1

1.1 Status of Public Art on the London Underground

The London Underground has been home to many outstanding public artworks in the subway space for over 150 years. After the 21st century, Transport for London funded the establishment of the Art on the underground program1 managing contemporary art projects in the underground. For more than a decade, it aims to raise millions of passenger's daily ride experience with extraordinary contemporary art and to change the way people feel about the city by collaborating with famous artists. They consider art as a crucial element of London's transportation, allowing passengers and their employees

to share art. The form and content of these art projects are diverse, including murals, installation art, concept art, etc. Since 2000, about 280 artists have participated, 190 projects have been conducted, including permanent and temporary ones. Besides public artworks, the program team also launched London Tube maps with various artists' design collaboration.

The London Underground Art Program is run by a dedicated group named Art on the underground. The program invites top artists from the UK and the rest of the world to create public art for the London Underground and claims to make the London Underground art stand out in the forefront of contemporary art on the debate how art shapes public spaces. It is funded by the Transport for London; some projects also received funds from the British Arts Council and some special projects can be funded by cooperative companies. The program team is a professional management team, including the planning team chairman, art planning and assistant, technical project manager, project manager, and an expert advisory committee. Its members are from the Transportation Bureau and several workers from social, cultural, artistic institutions, such as the London Transport Museum, the School of Modern Art, the Tate Modern, the Art and Business Organization, the Royal College of Art and other professional art institutions that guide the project. The program set up an official website and is also in charge of designing the Tube art map.

In aspects of the author and the content of these projects, London underground art is highly professional. The Art Project group has given the artist a high degree of freedom in their creative process. Even though they invited foreign artists to work with London Underground, the projects mostly concern the local history and culture. Artists experience the local culture, then blend it with their art style and re-create traditional

content through contemporary expressions, such as the large-scale public art project "The Bower of Bliss". Alongside with the history of the region and the 18th century English garden tradition, the artist wants to create a calm and peaceful “refuge” for passengers in the busy downtown; in another case, the art project is based on subway staff. The one called “London Underground: Brixton Station and Victoria Line” reveals the appearance of the underground staff. Its author is inspired by the famous murals from the Brixton area in the 1980s, and she showed the underground staff of Victoria Line in murals in the entrance area. This work deepened the staff’s sense of belonging to the station. In the innovation of form, artist Laure Prouvost created posters for electronic screen and a cover of six million underground maps in this commission: "You are more profound than you think", as well as the main installations in Heathrow Station and Radford Station which is connecting the East and West of London. It is an ambitious project with a series of posters across the city, covering the advertising outlets of all 270 stations in London. Similar works include Mark Wallinger's Labyrinth. It can be seen that the London underground Art program is dedicated to exploring the possibilities of London and everyday life with art. Notably, artists who work with the commission of Art on the underground can create one or more series based on the same theme at one or more sites. More details of each current and upcoming artworks can be found below in Table 1.

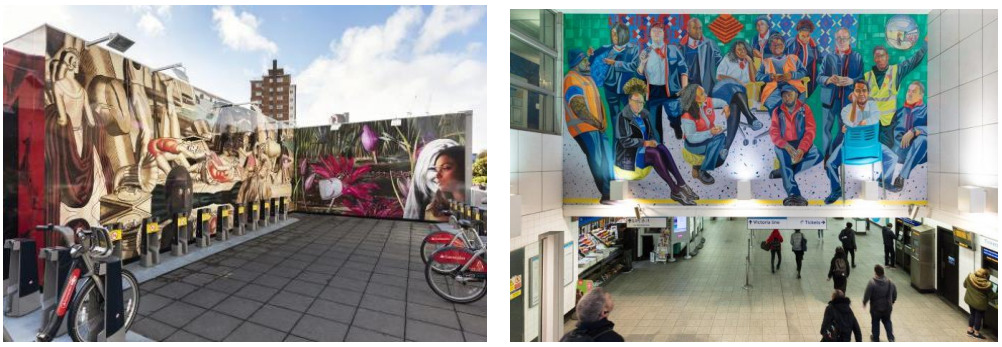

Figure 2. The Bower of Bliss by Linder Sterling (Left) and London Underground:

Brixton Station and Victoria Line by Aliza Nisenbaum (Right).

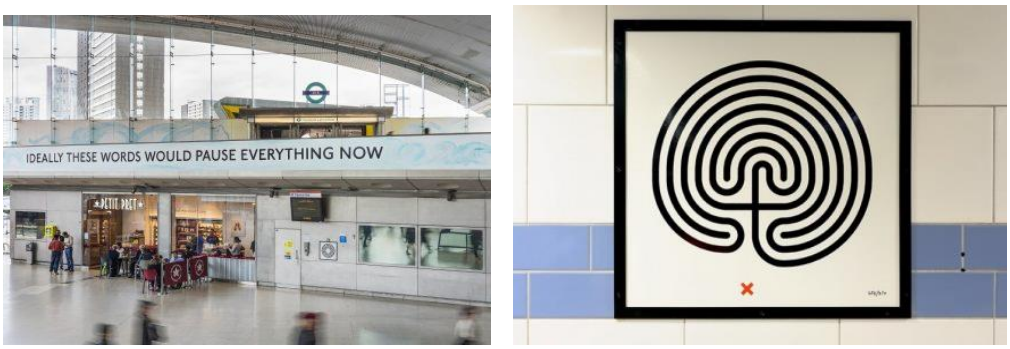

Figure 3. “You are deeper than what you think by Laure Prouvost (Left) and Labyrinth by Mark Wallinger (Right).

Note: Photos of current projects. Retrieved from https://art.tfl.gov.uk/projects/

1.2 Status of Public Art on the Wuhan Metro

Wuhan earliest rail transit Line 1 started in 2004, and the first metro is Line 2 opened in 2012. So far, nine lines are in operation, in which more than fifty art-featured stations have been built, with the proportion of art-featured stations reaching nearly 23%. Some operating lines and the lines under construction have also begun to collect design proposals. Among them, the six art-featured stations on Line 2 were the first batch. The research and design team are formed by Wuhan Metro Group Co., Ltd2 and Hubei Institute of Fine Arts (HIFA) Culture Development Co., Ltd. This team is responsible for the design process and construction of 6 art sites on Line 2. The public art forms of Wuhan Metro mainly include murals, installations, children's paintings, etc. The themes crossed history, traditional culture, modern society, new technology and others.

Table 1: Current London Underground Contemporary Art Projects （August 2019）

	Project	Site	Author	Date	Concept
1	Brixton Blue	Brixton	Denzil Forrester	2019.09.19 -2020.09	The artist responds to the diverse narratives of murals in the 1980s, the rapid development of the region, and the broader social and political history of mural production.
2	You are deeper than what you think	270 Sites	Laure Prouvost	2019.07.20 -2019.12.15	The artist uses his own logo painting techniques and the history of the early signs of navigating and graphic design in the London Underground. Every piece includes a digital poster of hand-painted logos, which is a sentence designed with iconic Johnston fonts and a company logo.
3	London Underground: Brixton Station and Victoria Line	Brixton Station	Aliza Nisenbaum	2019.04.10 -2019.09.16	Inspired by the famous murals of the Brixton area in the 1980s, art here explores how the artist sketches the utopia of future unity and belonging.
4	Brixton Mural Map	Brixton		2018.09	Printed a well-designed map of the existing murals in the Brixton area to help citizens discover and feel public art.
5	The Bower of Bliss	Southwark Station	Linder Sterling	2018.11.08 -2019.10	Using the history of the local area as a clue, combined with the concept of the 18th century English garden, the artist created a calm and peaceful harbor.

6	‘Diamonds and Circles’, works ‘in situ’ (Permanent)	Tottenham Court Road station	Daniel Buren	2017.07.03	Using the concept of shape, color and stripes, the artist creates diamond shapes and circular pattern on the glass wall of the station, which guides the audience to think about the physical space of the station.
7	Underline: Assemble and Matthew Raw (Permanent)	Seven Sisters Station	Assemble, Matthew Raw	2017.12.14	As part of the renovation of station, at the entrance of the Seven Sisters subway station which was vacant for more than a decade, the artists produced more than a thousand handmade tiles for the project,
8	Paolozzi Restoration at Tottenham Court Road station	Tottenham Court Road station	Eduardo Paolozzi	2017.02	Produced by Paolozzi renovating the mosaic murals in 1986 at the Tottenham Court Road Station, the work reflects the artist's interpretation of the local and artist’s huge interest in mechanization, urbanization, popular culture and daily life.
9	Beauty < Immortality (Permanent)	Piccadilly station	Langlands & Bell	2016.11.07	A wall installation that commemorates the 75th anniversary of Frank Picker, the CEO of the London Transport.

10	Underline; Design Work Leisure (Permanent)	Blackhorse Road, Victoria and Vauxhall stations	Giles Round	2015-2019	The project presents Frank Pique's contribution to London Underground. His design heritage: Johnston fonts and a subway map designed by Harry Baker in the early 20th century.
11	Labyrinth (Permanent)	270 Sites	Mark Wallinger	2013.02.05	To commemorate the 150th anniversary of the London Underground, explore a poetic connection through the rich graphic language history of the system.
12	Wrapper (Permanent)	Edgware Road station	Jacqueline Poncelet	2012.11.20	In order to cover the new buildings and façades next to the station, the community is integrated into a unified and comfortable visual experience, and the building is more partially observed, not the whole.
13	Sea Strata (Permanent)	Green Park Station	John Maine	2011.10.19	According to the characteristics of the site, it reflects the wall sculpture of the transition from urban to rural areas. The artist uses Polish stone to explore the natural composition of the rock, revealing the inside of marine life in 150 million years ago and mapping the internal structure of the material.

14	Full Circle (Permanent)	King's Cross St. Pancras Underground station	Knut Henrik Henriksen	2011.06.10	The permanent installation is designed to connect the two-ticket office space, based on the circular end wall of the subway tunnel, made with the same material of that space and represented the missing part of the underground. The work is clam and elegant.

Source: Art on the underground, Transport for London, https://art.tfl.gov.uk/

Looking closer at the works in Wuhan Metro, it is evident that the giant art wall (including murals, reliefs, wall installations) is the primary expression of Wuhan Metro Art Projects. Their contents mainly involve traditional culture, natural scenery, urban scenery, humanities, science and technology. These works present various aspects of this modern metropolis. The theme "Red Shouyi" includes a large-scale wall installation in the Shouyi Road Station on Line 4, to commemorate the critical historical event —— the Xinhai Revolution launched in Wuchang. The artworks were made of red bricks in different sizes. The words "Xinhai Shouyi-1911" symbolize the immortal spirit and grandeur of revolutionary enthusiasm. There are also some themes based on Hankou history and culture, for instance, the Hanzheng Impression in Hanzheng Street Station on the 6th line, the "Jianghan Memory" of Jianghan Road Station, and the "Guwusheng Impression" of Wusheng Road Station. In terms of the appearance of the city, the "Fashion Jincheng" of Jianghan Road Station on the 2nd line is one of the earliest such works. It is a vast scale work with Jianghan Road as the background, depicting the vivid scenes of daily life in Wuhan, inspiring people to reflect on daily life. There have been more and more works showing the future of science and technology in the past two

years. The dome has been applied as a new element to the top of the hall in the transfer station on Line 7 and 3. There are a few similar works such as the main dome in Line 11 Guangguqi Road Station, the 2D code ceiling unit of Line 4, etc. In Table 2, basic information of all the current art station I gathered from official news are shown, and I have visited every station personally in order to observe each artwork in its real size.

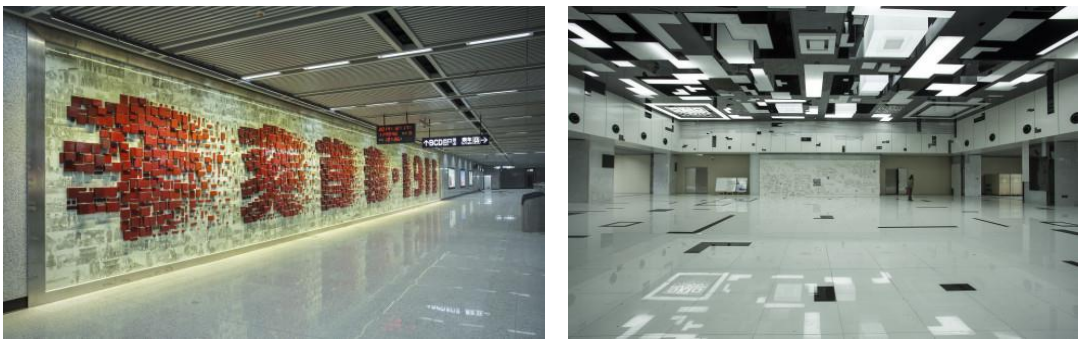

Figure 4. "Red Shouyi" in Shouyi Road Station (Left) and "Fashion Rhythm" in Wangjiawan Station (Right).

Note: Photo of “Red Shouyi" and "Fashion Rhythm". Retrieved from http://whgs.hifa.edu.cn/bmxw/26189.htm

2 Comparison and Analysis of Art Form

The research object of this paper is the public art of the metro, which does not focus on the concept and meaning of the artworks, but the form of them. As substantial economic and cultural differences remained in each society, the concept and meaning of the artworks are restricted by local history, culture and other factors, but its art form can be discussed and changed through rigorous researches, a creative and reasonable art form would evoke proper aesthetic feelings by establishing a new order in artworks. As the artworks in London and Wuhan metro have been separately demonstrated in the previous paragraphs, this part of the paper will analyze some representative artworks via

categorized comparison.

Table 2 : Wuhan Metro Contemporary Art Projects（August 2019）

	Line 2	Line 3	Line 4	Line 6
Art Site	12	8	9	11
Project & Station	"Neon Flower Rhyme" Yuxiong Road Station "Future node" Optics Valley Avenue Station "Lingdong Guanghua" Optics Valley Railway Station "Chu Feng Ancient Rhyme" Hongshan Square Station "Quiet Zhiyuan" Baotong Temple Station "City of Technology" Optics Valley Square Station "Jiangcheng Impression" Hankou Railway Station "Happy Wuhan" Zhongshan Park Station "Fashion Jiangcheng" Jianghan Road Station Tianhe Airport Station	"Light of movement" Dongfeng Company Station “Waterscape New Rhyme” Sixin Boulevard Station “Colorful star space” Wuhan Business District Station "Finding dreams" Hong Kong Road Station "towards warmth" Zhaojiatiao Station "Golden Years" Erqi Xiaolu Station "Flourishing Home" Citizen's House Station "Baiye Hongtu" Hongtu Boulevard Station	"Chu Han Xinghe" Wuchang Railway Station "East Lake Beauty" Yuejiazui Station "Urban Mountains and Seas" Iron machine station "Glorious years" Renhe Road Station "Red Shouyi" Shouyi Road Station "Revival road" Fuxing Road Station "Alpine ancient rhyme" Zhongjiacun Station "Zhang Gong Duo E" Wulidun Station "Fashion Rhythm" Wangjiawan Station	"view thousands" Guobo Center South Station "enjoyable Ocean" Guobo Center North Station "Watery companion" Qintai Station "Gu Wusheng impression" Wusheng Road Station "Han Zheng Impression" Hanzheng Street Station "Liudu memory" Liuduqiao Station "Jianghan Memory" Jianghan Road Station "With each passing day" Dazhi Road Station “Old Village New Residence” Shiqiao Station "Wanjia Lights" Evergreen Garden Station

	Julong Boulevard Station			"Flowers are like flowers" Yuanboyuan North Station
	Hongtu Boulevard Station			
Date	2012、2019	2015.10.9	2014.12.28	2016.12.28
Form	Wall installation	LED Wall installation	Wall installation	Wall installation
	3D installation	LED installation	LED installation	Overall Design
	Children's drawing	Dome		
Theme	Culture, City, Technology	City	Culture, Natural Environment	Culture, Natural Environment
	Line 7	**Line 8**	**Line 11**	**Luoyang Line**
Art Site	5	4	3	1
Project & Station	“Colorful star space” Wuhan Business District Station "Finding dreams" Hong Kong Road Station "Top Gun" Wangjiadun East Railway Station "Green technology" Yuanboyuan North Station "Phoenix Nirvana" Garden Expo Station	“Greenway Walk” Liyuan Station "The shed builds a new glow" Xujiapeng Station "Iron army Soul" Huangpu Road Station "The Yangtze River Spindle" Zhuyeshan Station	"Lingdong Guanghua" Optics Valley Railway Station "True urban view" Guanggu Wulu Station "Spirit of the World" Guanggu Qilu Station	“Prosperous” Xinrong Bus Terminal
Date	2018.8.29	2017.12	2018.8.7	2017.12
Form	Wall installation	Wall installation	Wall installation	Wall installation
	LED installation	Overall Design	Dome	Overall Design
	Dome			
Theme	City, Technology	City	City	Abstract

Note: I gather and sort out the information in person.

2.1 The Intrinsic Form and External Form of London and Wuhan Metro Public Art

The form of artwork subdivides into an intrinsic form and an external form. The intrinsic form refers to the internal construction of the work, and the external form refers to the external mode of its existence.

2.1.1 The Intrinsic Form of Murals

I visited and photographed the current open art stations in Wuhan Metro. In the investigation, I found that giant murals have become the most common and vital art form of Wuhan Metro. Every art station has at least one colossal mural, which is about 60 meters in length and 3 meters in height, with rich contents and materials, but the art forms are quite similar. There are two primary intrinsic forms of these murals: one is to simplify, transform, juxtapose and combine traditional cultural elements with symbolic meanings. Such works can be regarded as descriptive paintings of historical events and traditional culture. Use graphics such as simplified or stylized characters or buildings; the other is to create abstract paintings with simple materials and repeating patterns to decorate the metro space.

This first type of art form is descriptive painting which re-creates the traditional cultural elements with the modern expression technique. We can see from the works that the team is willing to demonstrate traditional cultures, such as murals in Wusheng Road Station, Liyuan Station, Guobo Center South Station, Shiqiao Station, containing many traditional cultures and artistic elements such as ancient architecture, ink painting, ancient trees, streets, etc. While trying to reproduce the tradition, they have recreated it with modern techniques. From the perspective of decoration and knowledge popularization, such combination of content and form seems to be understandable, but

from the perspective of painting, it cannot evoke many aesthetic feelings of the viewer. The British aesthetician Clive Bell in his theory of significant form, states that: in descriptive painting, the form is not used as an object of expressing emotion, but as a means of suggesting emotion or conveying information. Psychological and historical oriented portraits, topographical works, storytelling and suggestive contextual paintings and illustrations are all “descriptive paintings”.

On the one hand, as such murals in the Wuhan Metro are not genuine traditional art, but merely a reproduction of traditional art, they cannot adequately express traditional art and cannot be freely made at the same time. Bell believes that if a form of reproduction has artistic value, it is of a form, not as a reproduction. For instance, there is an art project “Paolozzi Restoration” at Tottenham Court Road station in the London Underground, but the project is about repairing a real artwork “Paolozzi's mosaic murals” completed in 1986, which Wuhan modern metro does not have. It is worth noting that there are many mosaic murals both in London and Wuhan Metro, but those in Wuhan are limited to depict urban or natural scenery in a realistic style with mosaics, such as murals in Hankou Railway Station, Yuejiazui Station. The mosaic murals of the Wuhan Metro are more focused on enriching the formal diversity of the overall metro artwork, rather than exploring the art form itself.

Secondly, in term of non-descriptive abstract paintings, Claire Bell sees the form itself as an end. He is not concerned with making arts, but by capturing the mysterious meaning behind the form that can bring emotion to people. When analyzing and comparing the other type of Wuhan murals, I found that the choices of materials for many abstract murals are based on Chinese literary meanings and pursing visual effects at the same time. For example, the murals of Xinrong Bus Terminal, Qintai Station and

Liuduqiao Station. This way of art creation uses materials as a visualized code of text, juxtaposed them to gain the emotions that the author wants to deliver through the works, but artistic creations are not simple mathematical operations, and works are not just a visualized literature. In artistic creation, besides the literary meaning, the physical characteristics and visual psychological characteristics of the material, as well as the combination of materials, will have a meaningful impact on the aesthetic sentiment. Moreover, the emotions in abstract murals cannot accurately be described in words, just like music, so this kind of works should explore how to convey emotions through the form itself, rather than visually transforming specific content. In the works of meaning and text, the London Underground art project "You are deeper than what you think" is very representative, the intrinsic form of the work is the text itself, rather than transforming the text into visual graphics.

Besides, observing from the outside, these giant murals are placed in a fixed position, most of them on the wall which is opposite to the service center, and passengers can pass through it when they enter and exit the gate. The position and size of the work have defaulted, that is to say, the external form of the work is planned, rather than being determined by the creator during the creation process. The same size, the same spatial location, but the work is not from the same series or artist. Although such a model may not be harmful to those murals that represent traditional content, it will restrict those contemporary public artworks to a specific location and space, and as a result, some of them may fail to form a complete artistic expression. The intrinsic and external form of contemporary public artworks contains an ontology, especially those with abstract content. Even though the abstract works of some sites have achieved spatial extension in visual perception, such as extending the pattern to the ceiling, pillars and other areas near the murals, but the essence does not change. It just repeats the same

pattern in the adjacent space to create an immersive visual effect.

2.1.2 The External Form

The external forms of public art in Wuhan Metro mainly include murals, hanging installations, sculptures, and display window design. Compared to the art form in the London Underground, the variety of art forms here seems not to be abundant. The development of London underground art relies on London's profound artistic heritage. From traditional painting to contemporary art, London has a critical position in the history of art. Many professional art institutions and top art schools, as well as the aesthetic foundation accumulated by citizens over the years, have become the significant advantage of London underground art. For more than a decade, more than 190 projects have covered almost all kinds of external forms, and still continually exploring and experimenting with new forms. The following section lists some representative examples of art forms that can become references.

(1) Sound Art: project "Zoorama" plays the recording of wild animal sounds in the station space, similar to the theme of Sea Strata at Green Park Station, mix the urban environment with natural sound elements. The advantage of sound art is that sound can fill the space entirely, as long as it plays, and will gradually fade out when passengers walk away from it. It has no clear boundaries and is very good at creating an immersive experience.

(2) Writing: project “King’s Cross is Rising”, as well as the photography art project “Connected”, recorded and displayed the life and stories of the metro staff.

(3) Fashion: In order to adapt to the characteristics of the subway space, fashion art is displayed in the form of posters, those fashion posters are displayed at 15 sites and

replaced monthly during the exhibition.

(4) Knitting art：“Knitting Circle” is not only a project to exhibit knitting art, it also encourages people to participate and learn how to make it.

(5) Comic strip sequences: In the project “The non-savvy non-commuter”, the author speaks from the perspective of ethnic minorities in the public space, reflecting the publicity of public art. It depicts the busy commute scene and the psychological distance between the passengers.

(6) Performing Art: project “The New Transport Band” placed contemporary Gothic-style installations in the subway space alongside live performances. The artist chose three legendary musicians because of their tragically deaths. This kind of live performance is rare in domestic metro space nowadays.

(7) Designing the merchandise for the metro: The London Metro Art Project team launches multiple cover versions of paper-made subway maps each year, which are designed and produced by various artists. There are also illustrations and conceptual art based on metro maps. In 1913, graphic designer Edward Johnston was commissioned by the London Underground Company to design a sans serif font for the Underground. Johnston fonts have been used on the London Underground for more than 60 years.

In general, there is still an enormous potential to extend the external form of Wuhan Metro Art. However, in the process of extension, we must focus on the appropriate combination of local culture and suitable art forms, rather than intuitive application and imitation. Contemporary public art often stresses its site-specific feature, which makes the artwork become part of the atmosphere and context of the space.

2.2 Interaction as an Element of Art Form in Public Art Projects

In the 1960s, due to the decentralization and spatial expansion of urban space, social differentiation and the decline of urban centers were aggravated, which caused the academic community to reflect and study public space and public art. At the meanwhile, due to the rise of land art, performance art, conceptual art and installation art, the viewer's experience has become an essential issue for artists. Interaction becomes one of the crucial elements in the art form in recent years. The extents of interactive art in Wuhan metro art is relatively low. For example, Line 4 uses a two-dimensional code to promote traditional commercial features and brand with ceiling lights. Viewers can scan the code with their mobile phones. Expect this project, Wuhan metro art barely has other projects containing an interactive form.

The art on the London Underground art program makes the Underground into a space similar to a massive art gallery. Passengers are invited to freely participate in some interactive projects, such as workshops leading by artists, tours of urban art sites, activities of singing at the station, programs of making small art pieces for the station. These kinds of interactive activities could make viewers engaging with the artworks and metro space more and generate a sense of belongings among local passengers. The lack of formal diversity in Wuhan Metro may be attributed to the operational mechanism, but there is still much room for improvement in the level of artistic creation.

3. Conclusion

The purpose of this article is not to take the London Underground art as an icon or to deny all the efforts in Wuhan Metro art projects. It is undeniable that there are many excellent artworks in Wuhan Metro, such as the reproduction of ancient business street view at Hanzheng Street Station, the dome in Wuhan Business Center, the abstract

murals of Shiqiao Station, etc. This paper compared and analyzed the internal and external forms of public artworks in London Underground and Wuhan Metro, which focus on defining the current problems of public artworks in Wuhan Metro. Then it introduced and demonstrated the inspiring and innovative art forms in London Underground art. According to the comparative study of art forms, this paper also put forward some suggestions for the improvement and development of Wuhan Metro Art.

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Digital Morphogenesis Research and Design Implementation

(Parametric Design in the Field of Industrial Design)

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Abstract： This paper provides a literature review, describes the definition of Digital Morphogenesis and gives examples of some design studies. Digital Morphogenesis can be divided into Parametric design and Algorithmic design according to Prof. Neil Leach. However, the application of digital morphogenesis has emerged more in the realm of Architecture, keeping a distance from Industrial Design. The author discovered the gap between digital morphogenesis and industrial design mainly existed in Ergonomics and found new ways of digital morphogenesis research and introduced a series of new instruments building a new procedure of industrial design with it.

Keywords: Digital Morphogenesis, Parametric design, Algorithmic design, Ergonomics, Tangible interaction, Generative design.

1 Introduction

With the rapid development of cutting-edge technologies such as Artificial Intelligence, Parametric Design, Digital Fabrication, etc. The definition of digital design could vary. Gilles Retsin, the program director of the BPro program at Bartlett UCL, raised the topic of “we have never been digital” on his exhibition of “Discrete Design” in Miami on October 30th, 2017. The statement of him and his partners is as following: ‘Architecture has never been digital: despite the use of computers to calculate huge amounts of complexity, the way that we build is still analogue, and therefore our increasing computational power is merely used in a representational way. The term ‘digital fabrication’ is misleading as well; 3d printing is an analogy process, similar to the way the CNC mill automates an artisanal action…’. Gilles is debating for his discrete design, which he believes could lead to high efficiency of automatic design and

automatic manufacture. Whether it's convincible or not, it does remind us about something and maybe a shock to us high spirited ones designing with computers. How should we define "digital design"? where is the turning point? Have we been on the road to be digital? Have we experienced it even before we noticed it? How much further could we go? This paper will use the concept of "Digital Morphogenesis" to explore and conduct further research.

2 Research Questions

However, the application of digital morphogenesis has emerged more in the realm of Architecture, keeping a distance from Industrial Design. The gap between digital morphogenesis and industrial design mainly existed in Ergonomics and found new ways of digital morphogenesis research and introduced a series of new instruments building a new procedure of industrial design with it. Therefore, the following research questions were of particular interest:

(1) Research on digital morphogenesis applied in the industrial design based on ergonomics and user experience.

(2) Appling the methods and instruments of tangible interaction into the design research.

(3) Utilizing the power of computation to generate designing forms.

(4) Considering suitable ways of digital fabrication to implement designs.

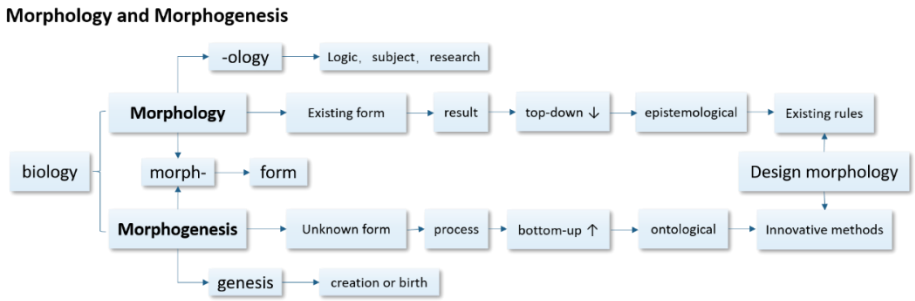
3 Literature Review

3.1 Morphogenesis and Morphology

The "Morphogenesis" is a word biologist commonly employ to refer to that shaping of developing tissues into recognizable forms such as those of particular bones, muscles, and the like.(Rene Thom,1972) The Art and Design Morphogenesis research, as Herbert A. Simon has said, is the task of natural science: to show that the wonderful is not

incomprehensible, to show how it can be comprehended – but not to destroy wonder. For when we have explained the wonderful, unmasked the hidden pattern, a new wonder arises at how complexity was woven out of simplicity. The aesthetics of natural science and mathematics is at one with the aesthetics of music and painting – both inhere in the discovery of a partially concealed pattern. (Herbert A. Simon,1996)

The difference between morphology and morphogenesis is, on a first level, a temporal one. Morphology, which derives from the Greek words morph ê and logos, comes into play when the form –morphe– is already there; and logos is the discourse or the cognitive construct that describes the form of an artefact after it is created. Morphogenesis, on the other hand, has as its second morpheme the Greek word genesis which means creation or birth. Therefore, it moves back in time and goes to the very moment that form is generated. Consequently, in order for morphology to take place, a morphogenesis has to precede. In biology, this temporal relation between the two is clear: Morphogenesis is the biological process that causes an organism to develop its shape. Morphology is the branch of biology that deals with the form of living organisms, and with relationships between their structures. Therefore, form is created (morphogenesis)and then form is studied(morphology). In other words, morphogenesis is ontological, whilst morphology is epistemological. This is through the description of how the shift from morphology to morphogenesis have marked a shift in the general understanding of form. Where Morphology concerns itself with the syntax of predefined, archetypal architectural form from the top-down, Morphogenesis moves towards an understand of generative form production from the bottom-up. That shift creates a new condition for the architect to operate in. (Maria Voyatzaki, Dimitris Gourdoukis,2018)



3.2 Digital Morphogenesis

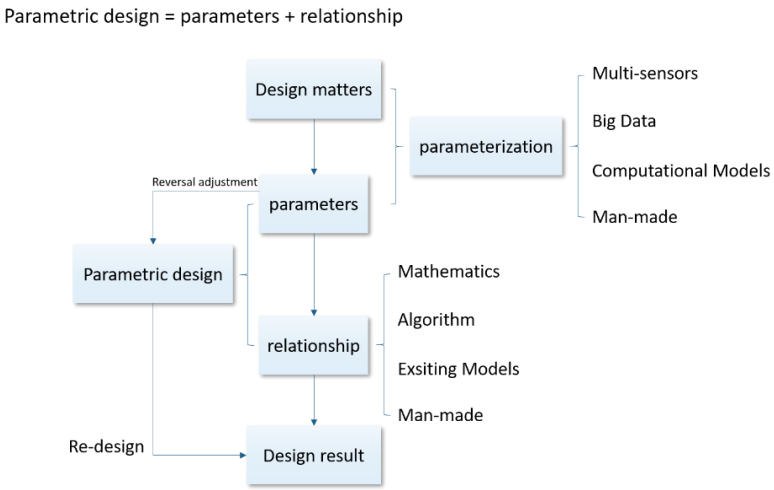
In contemporary design, digital media is increasingly being used not as a representational tool for visualization but as a generative tool for the derivation of form and its transformation-the digital morphogenesis.(Branko Kolarevic,2003) Taking its inspiration from biology, digital morphogenesis operates through a logic of optimization.it seeks to challenge the hegemony of top-down processes of form-making, and replace it with a bottom-up logic of form-finding. (Neil Leach, 2006) Digital design practice is in a state of rapid evolution, only recently have two distinct and potent design sensibilities - parametric and algorithmic design - emerged. (Neil Leach,2014)

3.2.1 Parametric Design

Basically, the term parametric originates from mathematics, and refers to using certain parameters or variables, which can be amended in order to manipulate with the equation results.(J.Frazer,2016) Accordingly, the principle of parametric design can be defined as mathematical design, where the relationship between the design elements are shown as parameters which could be reformulated to generate complex geometries, these geometries are based on the elements' parameters, by changing these parameters; new shapes are created simultaneously.(Ahmad Eltaweel, Yuehong SU,2017)Parametric design is a process based on algorithmic thinking that enables the expression of parameters and rules that, together, define, encode and clarify the relationship between

design intent and design response.(Wassim Jabi,2013)

With development of advanced parametric design systems and digital techniques, a new global style for the contemporary design - Parametricism - emerged, which has become the dominant, single style for avant-garde practice today and succeeded Modernism as the next long wave of systematic innovation. (Patrik Schumacher, 2009) Besides the architecture and urban design, parametric design methodology is used in many fields, disciplines which consist of complex algorithmic relations, interdisciplinary work, creative forms, and multiprocessing treatments. (Ahmad Eltaweel, Yuehong SU, 2017)



3.2.2 Algorithmic Design

With the development of information technology, the ideas of programing and mass calculating, such as Artificial Intelligence and Machine Learning, were introduced into the design field, resulting in the upcoming of computer-aided design and inspiring in understanding the designing behavior of human. (Weixin Huang, Hao Zheng,2018) Our understanding of design as a process and our ability to model it are still limited, one of the major strands of algorithmic design research is concerned with developing computational symbolic models of design processes to produce a better understanding of design and producing useful tools to aid human designers and in some areas to

automate various aspects of the design process.(John Gero,1991) The articulation of the Science of Design by Herbert Simon and the paradigmatic relevance of Artificial Intelligence in that context are closely intertwined topics: Simon elaborates the 'Sciences of the Artificial' in the context of the design of artefacts. Situated in this AI-centric view of design, we characterize "Algorithmic Design" as a specialization concerned with the development of the general representational and computational apparatus necessary for solving modelling and reasoning problems in design. (Mehul Bhatt, Christian Freksa,2014)

4 Research Focus

4.1 Digital Fabrication

Digital morphogenesis can be involved in exploring the potential use of digital fabrication, such as 3D printing, computer numerically controlled milling, along with other robotically controlled manufacturing operations, such as laser cutting, bandsaw cutting, stitching, weaving, forming, bending, folding and stacking. (Philip F. Yuan, Neil Leach,2018)

4.2 Ergonomics

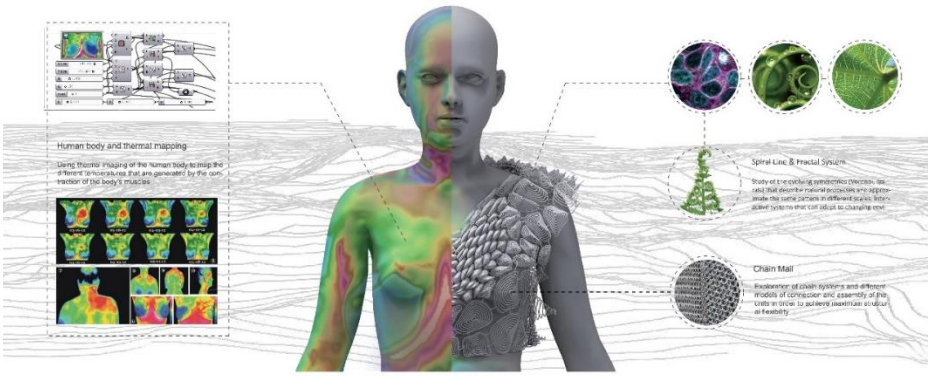
Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance. Ergonomics is a systems-oriented discipline which now extends across all aspects of human activity. Domains of specialization within the discipline of ergonomics are broadly the following: Physical Ergonomics, Cognitive Ergonomics and Organizational Ergonomics.(International Ergonomics Association,2018) Ergonomics is about 'fit': the fit between people, the

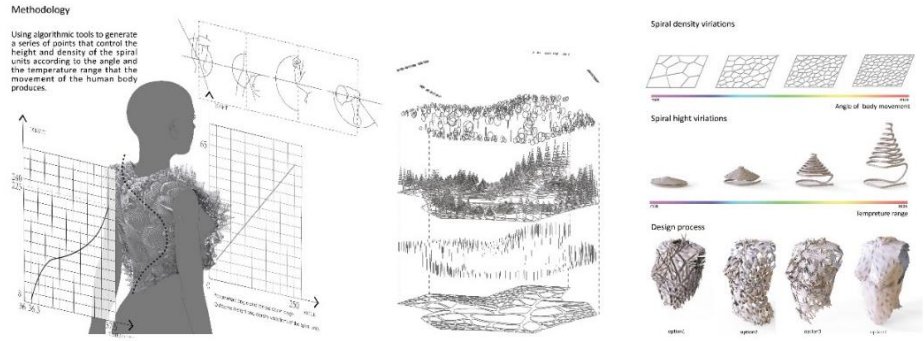
things they do, the objects they use and the environments they work in. (George Adu, Sylvia Adu, Paul Inkum, 2018) With the development of digital technologies, ergonomics parameters and human body dimensions can be measured indirectly using a 3D scanning method. (Stanci c, Musi c, and Zanchi 2013; Lee and Wang 2015) We can develop a parametric model to optimize products virtually in terms of ergonomics and comfort, and use the result of analysis to support the product developer to improve the man-machine interaction of products. (A. Wolf, S. Wartzack, 2018) However, the existing paradigm of ergonomics is worth questioned. Complexities of systems thinking, a currently ubiquitous ergonomics paradigm, was outpacing the capabilities of our methodological toolkit. (Paul M. Salmon, Guy H. Walker, Gemma J. M. Read, Natassia Goode and Neville A. Stanton,2016)

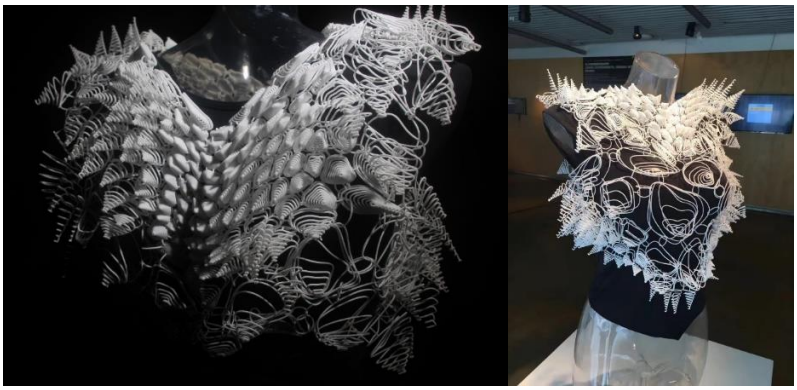
Ergonomics implementation:3D-Printed Body Architecture.

'3D-printed body architecture' could be defined as 3D-printed designs by architects for clothing, shoes, food, chairs and other items either for the human body, or at the scale of the human body. While the term itself is new, it nonetheless builds upon a number of existing traditions–the relatively recent history of 3D printing, and the longer-standing history of exploring the relationship between the human body and architecture. (Behnaz Farahi, Neil Leach, 2017)

In 2017, I participated in 3D-printed body architecture workshop hosted by Dr. Behnaz Farahi and Prof. Neil Leach at Tongji University in Shanghai. In this project, based on grasshopper platform, I used human body thermal map and ergonomic parameter model to design fashion clothing.







4.3 Tangible Interaction

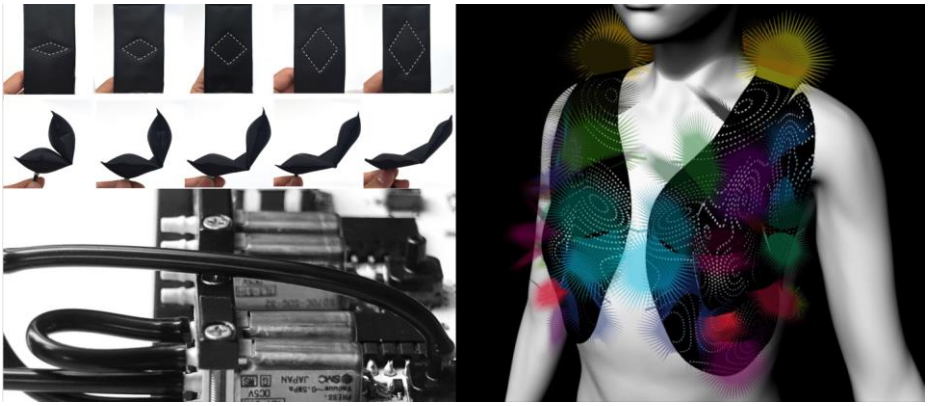
The growing number of ubiquitous and embedded computing technologies introduces a new paradigm for how we interact and communicate with the physical world. Interactions are no longer limited to those of people interacting with an object, environment or building, but now can be carried out as part of a larger ecosystem of connected objects, environments, and buildings that autonomously interact with each other, which is the tangible interaction. the field of industrial design came to engage with tangible interaction out of necessity as appliances became progressively

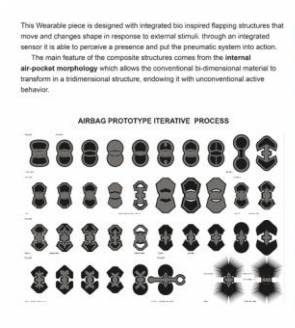
“intelligent”, containing more and more electronic and digital components. (Michael Fox,2014)

Tangible Interaction practice: Pneumatic Wearables.

In 2018, the Pneumatic Wearables workshop was guided by Dr. Behnaz Farahi and Dr. Jifei Ou at Tongji University in Shanghai. The pneumatic system was introduced in the workshop. Compared to the rigid actuation, a pneumatic-based system is light-weight and provides adaptable morphology. During the workshop, we learned about the pneumatic components such as valves, fittings and air logic. Through the exploration phase, we also understand the advantages and limitations of the pneumatic-based actuation. Using algorithmic design, we simulated various dynamic patterns and behaviors such as L-systems growth, cellular structures, and folding behaviors.

At the seminar, we were asked to explore functional, emotional and social aspect of augmentation. By using the prototyping platform Pneuduino, our project includes an interaction scenario using multiple sensors.



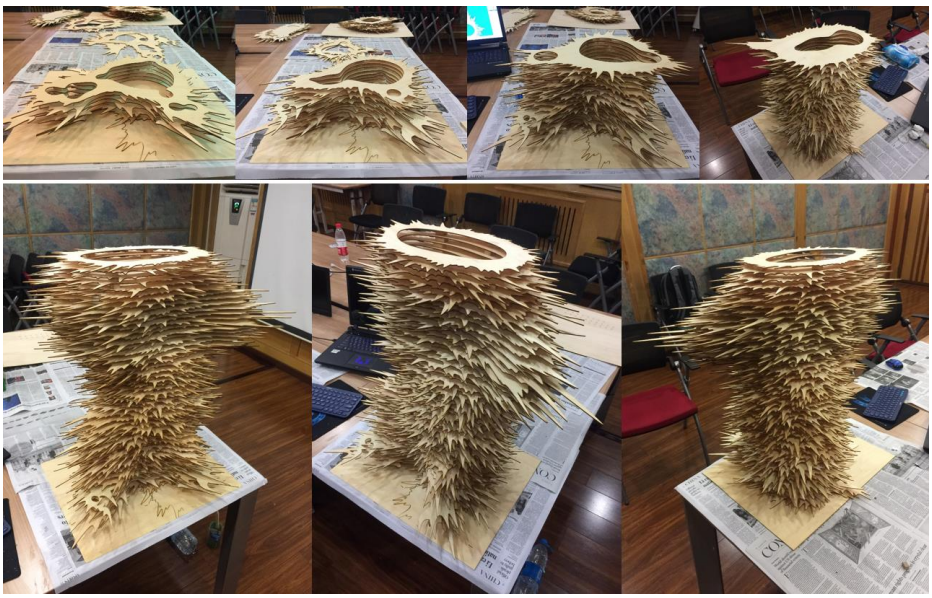


4.4 Generative Art

Generative art refers to any art practice where the artist uses a system, such as a set of natural language rules, a computer program, a machine, or other procedural invention, which is set into motion with some degree of autonomy contributing to or resulting in a completed work of art. (Philip Galanter,2003)

Utilization of computational capacity: Algorithmic Art.

The algorithmic art workshop was tutored by Diego Perez-Espitia at Tsinghua University in Beijing in 2018. The theme of the workshop is ‘from data to matter’. During the workshop, I used grasshopper as the computational tools to process the datasets of comets from NASA website and design an installation based on the data and my aesthetic concern. Using aesthetic and conceptual principles, the geometries were translated into experimental 2D and 3D art pieces by laser cutting with digital fabrication technology.



5 Research Gap

As mentioned above, in the study of digital morphogenesis, both parametric design and algorithmic design are more widely used in architecture and related fields, and in the

field of industrial design, they are much less popular than the former. There are many reasons behind this: first, in most cases, the research on digital morphogenesis was used to study how to "form finding". Researchers have placed greater emphasis on the "forms" of digital morphogenesis and the definition of "forms" in the occurrence of digital morphologies. However, dazzling shapes and complex structures are not accepted by the principles of "standardization" and "mass production" advocated by industrial design, so "digital design" has always been at a distance from industrial design. Second, industrial design is different from architectural design and fashion design. Industrial design emphasizes "ergonomics" and "user experience." There have been few studies on its digital morphogenesis. Third, the digital form takes more emphasis on technology and manufacturing, but it does not involve humanistic related fields such as "sociology", "anthropology" and "psychology" that industrial design focuses on.

At the same time, the branching "algorithm design" of digital morphogenesis is not only a hot topic in the current research direction, but also a difficult point in the research. It is not difficult to see. How to explore the potential of digital morphogenesis by information technology such as deep learning and artificial intelligence, which needs to be explored and researched.

6 Research Design

In this study, ergonomic experiments and design were performed using the principle of digital morphogenesis. In ergonomic experiments, using Arduino, Kinect and other intelligent tools, the experimental participants' behavior parameters were input into the parametric design software Rhino and Grasshopper, thus achieving the behavioral characteristics of the experimental participants. The most important content of this research is to design and implement parametric experiments, analyze experimental

results, and improve the design process.

6.1 Methodologies

When it comes to parametric design, a philosophic theory would be mentioned, that is "Becoming" according to Deleuze. The core content of "Becoming" is a generating with a bottom-up mean. For instance, when Gropius designed the roads of Disney Park, he didn't design that in person but let tourists enter and wander in the vacant lawn, to such an extent that those roads were generated spontaneously. Similarly, when Ma designed the Fish tank, he also used this methodology that he applied multi-sensors to capture and record the movements and trails of fishes, and using those data generating the tank design.

6.2 Instruments

Kinect for windows.

Kinect is the external somatosensory camera of Microsoft XBOX360. Players can play somatosensory games through it. However, the functions and applications of Kinect are far more than that. Since the release of Kinect in June 2010, professional netizens and programmers have been continuously researching and re-developing it. Therefore, Microsoft finally released Kinect for Windows in June 2011 for programmers to develop and Research on the PC platform.

Arduino with multiple sensors.

Arduino is a PC motherboard. It can connect to a variety of sensors, sense changes in the physical world, and produce a range of digital and analog signals. At the same time, we can identify and use the signals from Arduino through the Grasshopper plug-in Firefly to achieve the connection between the real physical world and the virtual digital

world. Compared to Kinect, Arduino is more basic and more primitive, and we are free to use a range of sensors to flexibly design the way they capture changes in the physical world. For example, we can only use Kinect to obtain the general body posture of the participants, and the details of the physical characteristics such as height and weight between the participants and the seat, as well as the value of mutual pressure, are very difficult. This is obtained separately from Kinect. We can use Arduino and a range of related sensors to help get these parameters.

6.3 Software

Grasshopper.

For designers who are exploring new shapes using generative algorithms, Grasshopper is a graphical algorithm editor tightly integrated with Rhino's 3D modeling tools. Unlike Rhino Script, Grasshopper requires no knowledge of programming or scripting, but still allows designers to build form generators from the simple to the awe-inspiring.

6.4 Ergonomics Designing Experiment

Participants.

Basic information of experimental participants :

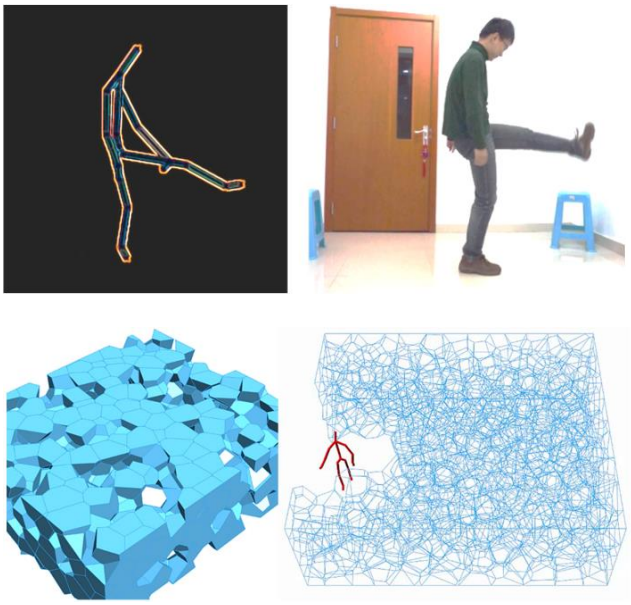
Name : Li Kang
Gender : male
Age : 26
Education : Graduate student of PKU

Birthplace : Jiaozuo Henan
Favorite design style : Minimalism
Hobbies : Music , Photography
Major : Low carbon Economics

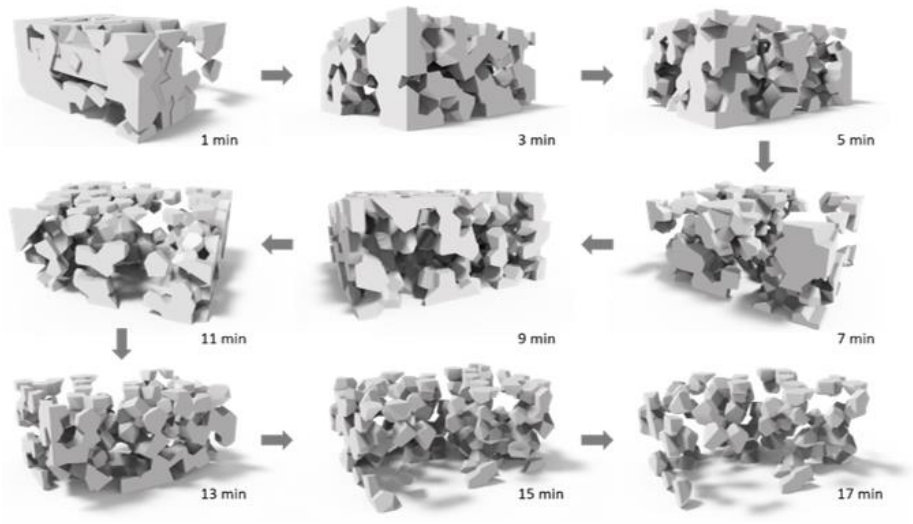
Procedure1: Spatial Design.

Participants were invited to move randomly and autonomously within a specified space (4 m * 2 m * 3 m) and perform certain physical behaviors. The Kinect somatosensory camera placed by the experimenter captured these actions and behaviors and transmitted them via the SDK to the Grasshopper software on the experimenter's computer. The Voronoi three-dimensional spatial architecture model was established in the Rhinoceros,

and the random deletion commands were used to randomly remove motion and behavior. Remove the Voronoi cells to complete the construction of a simple space. This space is automatically generated by the participants' behavior.

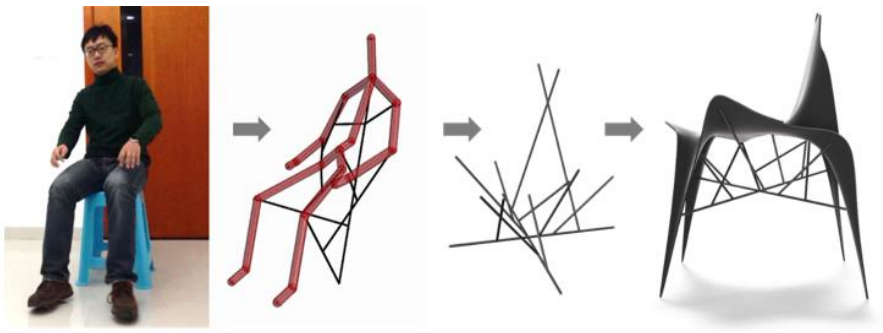


This experiment explores an innovative space design mode, that is, the application of Gil Deleuze's Becoming philosophy. In the process of space design, designers do not play an important role, but are user-centered. The shape of space changes with the user's behavior. In other words, this space is not designed by the designer, but by the user himself inadvertently.



Procedure2: Ergonomics Chairs Design.

Participants were invited to sit in four different chairs, relax and sit upright in the most comfortable position. The four seats are: hard with back, hard without back, soft with back, soft without back. At the same time, the participant's posture was captured by the Kinect somatosensory camera and recorded in the Grasshopper software. At this point, the experimenter recorded the most comfortable sitting posture by observing the data in the Grasshopper and communicating with the participants at the same time. Five sitting positions were recorded in this experiment. When recording a sitting position, the Grasshopper uses a pre-programmed procedure to create a suitable seat shape for the sitting position. This experiment divides the seat modeling into two steps: 1. On the basis of the sitting virtual skeleton, the pole is generated from the ten key points on the body to the center of the ground; 2. The membrane is generated by the pole generated by Grasshopper.



7 Result and Discussion

In the research process of digital morphogenesis, the author has been learning and practicing the application of intelligent tools in parameterization and algorithmic design research. Arduino, Kinect, and other hardware tools, as well as Firefly, Ghowl, and other software tools, were used and successfully transformed real-world physical changes into Grasshopper design parameters.

Parametric design experiments were designed and experimental participants

were invited to participate in the design process. The experimental process can effectively collect data and apply it to the integrated design, and finally get the satisfaction of the experimental participants who help the author to complete the design.

As important as parameter acquisition and that is the construction of parameter relationships, which is equivalent to the SOC integrated circuit professional data acquisition system. The Grasshopper make programming of the data acquisition system simple and friendly. Designers with non-computer backgrounds can quickly and easily learn visualization and node programming modes. At the same time, the Grasshopper has a powerful plug-in system that can satisfy almost all the designer's wonderful ideas.

8 Limitation and Implication

In fact, the author has little knowledge of computer knowledge and technology and is not free to code to create different forms of parametric design models. At the same time, the author has not fully understood the relevant knowledge of the various subjects involved in the research, which is very regrettable. For example, Druze's philosophy expounds the ontology of Becoming, discusses the way of existence and operational rules of things; fractal geometry explores the styling rules of all things in nature; topologically explores the relationship between things and the internal elements of things. Each of these disciplines has a value that takes a long time to learn and understand. For the sake of research alone, it is not enough for the author to have only one of them. What impressed me deeply was the dialogue between Patrick Schumacher and Neil Leach, from their debates, we can see how many cross-borders their knowledge structures exist. They include philosophy, sociology, economics, architecture, computer science, and mathematics.

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Study on Multi-constrainted Seat Layout Optimization of Aircraft Cabin Based on modeFRONTIER

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Abstract： This paper presents a mathematical model based on modeFRONTIER to research the optimization of aircraft cabin seat layout. The mathematical model analyzes the aircraft cabin seat layout from comfort, economy and security. And the corresponding constraints are set up to solve the three questions. Each constraint is calculated to get the objective function. Then modeFRONTIER is used on the computing of target function, and the optimal solution meeting the requirements is obtained after screening and statistical analysis. The seat layout of B737-800 is calculated by using the mathematical model proposed in this study, and the result is consistent with the current layout scheme, which proves the validity.

Keywords: aircraft cabin; modeFRONTIER; multi-constrained; seat layout; layout optimization

1 Introduction

Seat layout of aircraft is one of the important factors affecting cabin comfort. Besides comfort, seat layout also has important relationship with economy and safety of aircraft. After decades of development, many scholars still propose new methods to study cabin seat layout.

To research cabin layout optimization, researchers mainly study algorithms. A series of algorithms had been applied to research layout design and optimization. Saint-Jalmes proposed a new layout in 2008, which showed a set or assembly of aircraft seats to outfit an aircraft cabin, comprising at least two columns of neigh boring seats[1]. And in 2015, he proposed a new layout to provide an aircraft-cabin layout for which both the number of passengers able to travel in seated position and the number of passengers able to travel in lying-down position are optimized, which could also provide an enhanced comfort for the passengers since it should allow a larger number of them to be able to sleep in lying-down position[2]. Han X J described getting the most optimal solution of equipment layout in the aircraft cabin as a problem, which is abstracted as three dimensions (3D) layout problem, and a co-evolutionary particle swarm optimization with heuristic rules is presented[3].

In this study, cabin seat layout elements are analyzed firstly, multiple constraints on cabin seat layout elements is set up by applying genetic algorithm, and a general mathematical model for multiple optimization objectives is established, so that the cabin layout in multiple dimensions can be solved. The optimization of cabin seat layout is realized by using this model, and the rationality and feasibility is verified.

This paper is organized as follows: Section 2 describes the key elements of cabin seat layout from different angles. Section 3 establishes the general mathematical model

of cabin seat layout. Then the feasibility and rationality of the model are described in Section 4. And finally, conclusions are presented in Section 5.

2 Analysis of key elements of cabin seat layout

2.1 Comfort analysis

In cabin layout problem, the smallest layout unit is the space occupied by each seat, referred to as seat space[4]. The space is composed of seat and leg space. The longitudinal size is called seat row distance and the transverse size is called seat width. The influencing factors of cabin seat layout mainly includes seat number, seat width, seat height, weight, etc.

2.2 Economic analysis

Relevant studies show that the main influencing factors for airlines to choose cabin layout mainly contains passenger market demand, route distance and passenger market positioning, which could affect the income of airlines[5]. The economic requirements of cabin layout can be measured by the revenue of a single flight, which can be calculated by the following formula.

Revenue from a single flight= First class seats × average first class seats × average first class fares+ seat number of business class × average seat rate of business class × average ticket price of business class+ economy class seats × average economy class seats × average economy class fares.

2.3 Safety analysis

During the cabin layout design, we must consider the layout of emergency escape exits. Considering the actual situation of the passenger emergency evacuation time is

positively correlated with its emergency evacuation distance, the layout model studies emergency evacuation distance instead of emergency evacuation time, emergency exit rate and other safety indicators. The security optimal solutions are obtained through calculating the total distance, and the result should be as small as possible.

In addition, one question should be considered that the emergency escape time of the passenger aircraft depends on the largest one in the emergency escape time of the cabin at all levels. Therefore, while minimizing the total emergency escape distance of the passenger cabin, the largest one in the emergency escape distance of the cabin at all levels should also be minimized.

3 Mathematical model of cabin seat layout

Based on human body size, cabin size, cabin equipment and facilities size and other parameters, this study takes human-machine size constraint relationship as the core, and takes safety, comfort and economy as the optimization direction to build a general mathematical model. The main content is shown in figure 1.

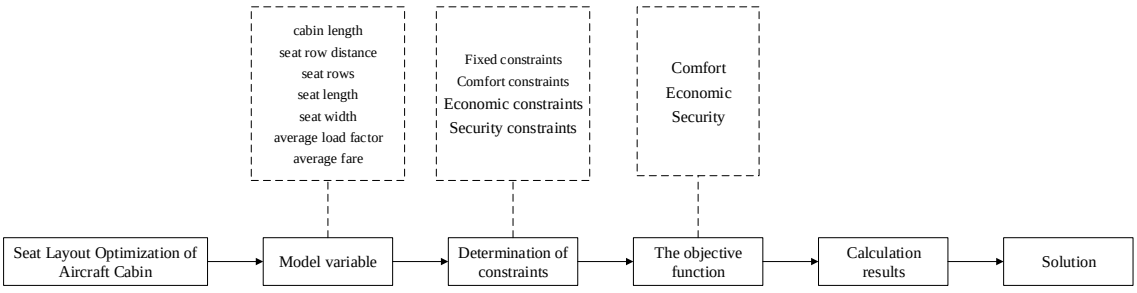


Figure 1. Optimization model of cabin seat layout

3.1 Model variable

Firstly, relevant variables are defined, including cabin length, seat row distance, seat row number, seat length, seat back length, seat width, average load factor, average fare and other basic variables, as shown in table 1.

Table 1. Variable of cabin layout optimization model

Cabin type	cabin length (m)	seat row distance (in)	seat rows (in)	seat length (in)	seat back length (in)	seat width (in)	average load factor (%)	average fare (¥)
First class-A	L_a	X_a	m	$l_{ch,a}$	$l_{r,a}$	$l_{w,a}$	u_a	P_a
Business class-B	L_b	X_b	n	$l_{ch,b}$	$l_{r,b}$	$l_{w,b}$	u_b	P_b
Economy extra-C	L_c	X_c	p	$l_{ch,c}$	$l_{r,c}$	$l_{w,c}$	u_c	P_c
Economy class-D	L_d	X_d	q	$l_{ch,d}$	$l_{r,d}$	$l_{w,d}$	u_d	P_d
Aisle width-E	E1, E2, E3, E4 equals to L_{e1}, L_{e2}, L_{e3}, L_{e4}							

In order to simplify the description and calculation of the model, this study further defines a group of constants, as shown in table 2. When the plane model is fixed, the constant value of this group does not change with the change of cabin layout. However, when the plane model changes, the values of these constants are allowed to be adjusted according to specific design requirements.

3.2 Determination of constraints

3.2.1 Fixed constraints

In this study, the fixed constraints of the cabin layout optimization design model consider the following conditions.

The sum of longitudinal lengths of each cabin shall not exceed the total length of the cabin. And meanwhile it should not be less than the total length of the cabin.

$$L_a + L_b + L_c + L_d + L_{e1} + L_{e2} + L_{e3} + L_{e4} = L \qquad (3.1)$$

Table 2. Constant of cabin layout optimization model

Symbol	Meaning	Unit
L	Cabin length	m
W	Cabin width	m
H	Cabin height	m
L_0	Typical size of kitchen & bathroom	mm
L_p	Aisle width	mm/in
l_0	Body length	mm
l_{ft}	Foot length	mm
l_{ba}	Baby chair length	in
φ	Seat back angle	°
θ	Angle of seat axis and course	°
l_{rh}	Seat back reclined dimension	in
W_a	Horizontal width of first class seats	in
W_b	Lateral width of business class seat	in
W_{ar}	Total width of seat armrest	in
α	Minimum comfort satisfaction of business class seat	—
β	Maximum comfort satisfaction of business class seat	—
a	Number of seats per row in first class	—
b	Number of seats per row in business class	—
c	Number of seats per row in economy extra	—
d	Number of seats per row in economy class	—

According to different layout, each cabin takes corresponding length. If a kind of cabin is not provided, the length of the class section can be set to zero. In general, the length of economy class is not zero.

$$L_a \geq 0，L_b \geq 0，L_c \geq 0，L_d > 0 \qquad (3.2)$$

The activity cabin (E1 and E2) is usually equipped with kitchen and lavatory units in addition to the access channel, so the length should be larger than the sum of the typical size of the kitchen and lavatory and the width of the access channel ($L_0 + L_p$). The length constraints of each activity cabin can be expressed as follows.

$$L_0 + L_{p,1} \leq L_{e1} \leq \max\{L_a, L_b, L_c, L_d\} \quad (3.3)$$

$$L_0 + L_{p,2} \leq L_{e2} \leq L_d \quad (3.4)$$

$$0 \leq L_{e3} \leq \max\{L_c, L_d\} \quad (3.5)$$

$$0 \leq l_{e4} \leq \max\{L_b, L_c\} \quad (3.6)$$

The constraints among cabin length, seat row distance and seat rows are as follows.

$$m \cdot X_a \leq L_a < (m+1) \cdot X_a \quad (3.7)$$

$$n \cdot X_b \leq L_b < (n+1) \cdot X_b \quad (3.8)$$

$$p \cdot X_c \leq L_c < (p+1) \cdot X_c \quad (3.9)$$

$$q \cdot X_d \leq L_d < (q+1) \cdot X_d \quad (3.10)$$

3.2.2 Comfort constraints

The seat row distance of economy class, economy extra, business class and first class should satisfy the following relationships.

$$X_d < X_c < X_b < X_a \quad (3.11)$$

Here, we take economy class as an example to conduct comfort constraint analysis, and other cabins adopt similar methods to make corresponding constraints. Baby chair space is provided at the front of economy class. The length of baby chair space is generally longer than the leg space of economy class seat at the back.

$$l_{ba} > l_{rm,d} \quad (3.12)$$

After taking the length of the baby seat space into account for the economy class layout.

$$\left(l_{ba} - l_{rm,d}\right) + q \cdot X_d \leq L_d < (q+1) \cdot X_d \qquad (3.13)$$

Given the legroom constraints, there is $l_{rm,d} = X_d - l_{ch,d}$, so the above equation can also be expressed as follows.

$$\left(l_{ba} + l_{ch,d}\right) + (q-1) \cdot X_d \leq L_d < (q+1) \cdot X_d \qquad (3.14)$$

$$l_{ba} = \max\left\{l_{ba}, l_{r,d} \cdot \sin\varphi_{max}, L_p\right\} \qquad (3.15)$$

Due to the design requirements of reachability, the limits of legroom length of economy class seats are as follows.

$$\min\left\{l_{ft}, l_{r,d} \cdot \sin\varphi_{d,max}\right\} \leq l_{rm,d} \leq \max\left\{l_{r,d} \cdot \sin\varphi_{d,max}, L_p\right\} \qquad (3.16)$$

Considering the seat row distance of economy class exists $X_d = l_{rm,d} + l_{ch,d}$, the seat row distance of economy class X_d should meet the constraint conditions as follows.

$$\min\left\{l_{ft} + l_{ch,d}, l_{r,d} \cdot \sin\varphi_{d,max} + l_{ch,d}\right\} \leq X_d$$

$$\leq \max\left\{l_{r,d} \cdot \sin\varphi_{d,max} + l_{ch,d}, L_{p,d} + l_{ch,d}\right\} \qquad (3.17)$$

For ease of understanding, the above equation can be expressed as follows.

$$l_{ft} + l_{ch,d} \leq X_d \approx l_{r,d} \cdot \sin\varphi_{d,max} + l_{ch,d} \leq L_{p,d} + l_{ch,d} \qquad (3.18)$$

3.2.3 Economic constraints

Target model, task type and market positioning can not only determine the constants related to the comfort and safety (cabin length L and width W, height H, typical size of kitchen and bathroom L_0, aisle width L_p, etc.), but also determine seat cross-section layout form (horizontal) and space classification (vertical). The common layout forms on the market can be summarized in table 3 for reference.

Table 3. Economic constraints

Type	Layout	Mass market	Balanced market	High-end market
Feeder liner	Horizontal	2-2 2-3	2-2 2-3	—
	Vertical	D B-D	B-D C-D	—
Narrow-body aircraft	Horizontal	2-2 3-3	2-2 3-3	2-2 3-3
	Vertical	D B-D	B-D A-B-D B-C-D	B-D A-B-D B-C-D
Wide-body jet	Horizontal	1-2-1，2-2-2 3-3-3，2-5-2	1-2-1，2-2-2 2-4-2，3-3-3	1-2-1，2-2-2 2-4-2，3-3-3
	Vertical	B-D A-B-D	B-D A-B-D B-C-D	A-B-D B-C-D

3.2.4 Security constraints

The safety constraints can be considered from the aspects of horizontal and vertical layout. For the horizontal layout of single-aisle passenger aircraft, the width of passenger channel for all levels of cabins shall meet the following requirements, in which a, b, c and d are the number of seats arranged in each row of each level of cabin.

$$L_{p,a} = W - a \cdot l_{w,a} \quad (3.19)$$

$$L_{p,b} = W - b \cdot W_b \quad (3.20)$$

$$L_{p,c} = W - c \cdot l_{w,c} \quad (3.21)$$

$$L_{p,d} = W - d \cdot l_{w,d} \quad (3.22)$$

For dual-aisle passenger aircraft, aisle width also meets similar requirements, but the number of aisles needs to be considered：

$$2 \cdot L_{p,a} = W - a \cdot l_{w,a} \quad (3.23)$$

$$2 \cdot L_{p,b} = W - b \cdot W_b \quad (3.24)$$

$$2 \cdot L_{p,c} = W - c \cdot l_{w,c} \quad (3.25)$$

$$2 \cdot L_{p,d} = W - d \cdot l_{w,d} \quad (3.26)$$

According to the relevant provisions of airworthiness regulations, the passenger aisle width must be larger than the minimum aisle width, so it is required that:

$$\{L_{p,a}、L_{p,b}、L_{p,c}、L_{p,d}\} \geq L_{p,min} = 15in \quad (3.27)$$

Another key factor of cabin longitudinal layout is the number of emergency exits. When arranging 2 emergency exits, the seat layout should meet the following requirements：

$$(l_{ba} + L_{p,min} + 2 \cdot l_{ch,d}) + (q-2) \cdot X_d \leq L_d < (q+1) \cdot X_d \quad (3.28)$$

Similarly, when there are 4 emergency exits, the seat layout should meet：

$$(l_{ba} + 2 \cdot L_{p,min} + 3 \cdot l_{ch,d}) + (q-3) \cdot X_d \leq L_d < (q+1) \cdot X_d \quad (3.29)$$

3.3 The objective function

3.3.1 Comfort

According to the comfort requirements, the sleeping posture space of first class and business class should be the larger the better, which means the seat row distance/body length should be the larger the better. Economy extra and economy class require more sitting room, which means legroom/body should be the larger the better. Therefore, the above ratios are defined as comfort coefficients of cabin seats at all levels, which can be

denoted as respectively.

$$C_a = \frac{X_a}{l_o} \text{?} C_b = \frac{X_b}{l_o} \text{?} C_c = \frac{l_{rm,c}}{l_{ft}} \text{?} C_d = \frac{l_{rm,d}}{l_{ft}} \quad (3.30)$$

Among them, $l_{rm,c} = X_c - l_{ch,c}$?$l_{rm,d} = X_d - l_{ch,d}$. Considering the proportion of seats in each cabin, the overall comfort coefficient of the cabin can be expressed as follows:

$$C = (a \cdot m \cdot C_a + b \cdot n \cdot C_b + c \cdot p \cdot C_c + d \cdot q \cdot C_d)/(a \cdot m + b \cdot n + c \cdot p + d \cdot q) \quad (3.31)$$

Take the objective function of comfort to be:

$$\max\{C\} \quad (3.32)$$

3.3.2 Economy

According to the above, the profitability of flights can be measured by revenue from a single flight. The calculation formula of revenue from a single flight can be expressed as follows.

$$M = a \cdot m \cdot u_a \cdot P_a + b \cdot n \cdot u_b \cdot P_b + c \cdot p \cdot u_c \cdot P_c + d \cdot q \cdot u_d \cdot P_d \quad (3.33)$$

Among them, a、b、c、d are the number of seats in each row of cabin A, B, C and D respectively. Seat rows are expressed as m, n, p and q. Average passenger load factors are expressed as $u_a \sim u_d$. Average ticket price is shown as $P_a \sim P_d$. With the goal of the best profit, M should be made as large as possible, so that the objective function of economy should be taken as follows:

$$\max\{M\} \quad (3.34)$$

3.3.3 Security

The model proposed in this study measures the safety of cabin layout by emergency

escape distance instead of emergency escape time.

Wide-body passenger aircraft is taken as an example in this model (figure 2). The exit in E1 is only for passengers in cabin A to escape, and the escape distance of the first row to the exit should be the sum of the width of passenger channel and 1 times seat spacing, denoted as $L_{p,1} + X_a$. The escape distance of the second row should be the sum of the width of the passenger channel and 2 times the seat spacing, denoted as $L_{p,1} + 2X_a$. Similarly, the escape distance of the last row (row m) should be $L_{p,1} + m \cdot X_a$.

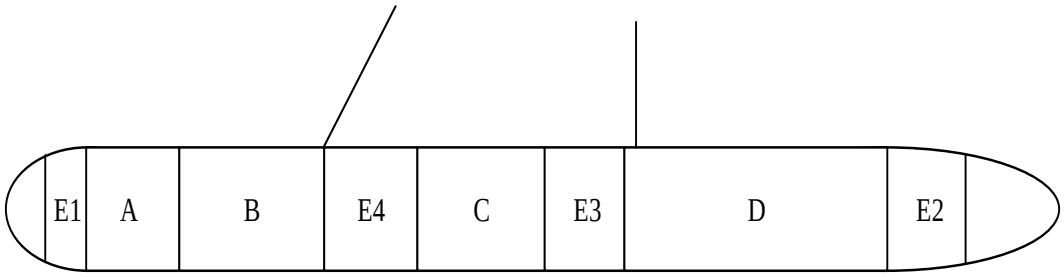


Fig. 2 Wide-body aircraft layout

To simplify the calculation reasonably, assuming that the escape distance of seats in the same row is the same, then:

The exit located in E1 corresponds to all passengers in cabin A, and its total escape distance is：

$$S_1 = a \cdot \left(m \cdot L_{p,1} + \frac{m(m+1)}{2} \cdot X_a \right) \qquad (3.35)$$

The exit located in E4 corresponds to all passengers in cabin B and half of those in cabin C, with a total escape distance of:

$$S_4 = \left(bn + c\left[\frac{p}{2}\right] \right) \cdot L_{p,4} + \frac{bn(n+1)}{2} \cdot X_b + c\left[\frac{p}{2}\right] \cdot \left(\left[\frac{p}{2}\right] + 1 \right) \cdot \frac{X_c}{2} \qquad (3.36)$$

The exit located in E3 corresponds to half of all passengers in cabin C and cabin D, and the total escape distance is:

$$S_3 = \left(c\left(p - \left[\frac{p}{2}\right]\right) + d\left[\frac{q}{2}\right]\right) L_{p,3} + c\left(p - \left[\frac{p}{2}\right]\right)\left(p - \left[\frac{p}{2}\right] + 1\right)\frac{X_c}{2} + d\left[\frac{q}{2}\right]\left(\left[\frac{q}{2}\right] + 1\right)\frac{X_d}{2} \quad (3.37)$$

The exit located in E2 corresponds to the remaining half of passengers in cabin D, and their total escape distance is:

$$S_2 = d \cdot \left(\left(q - \left[\frac{q}{2}\right]\right) \cdot L_{p,2} + \left(q - \left[\frac{q}{2}\right]\right) \cdot \left(q - \left[\frac{q}{2}\right] + 1\right) \cdot \frac{X_d}{2}\right) \quad (3.38)$$

In the above types, [x] represents the maximum integer which is not exceeding x, and a, b, c and d represent the number of seats in each row. The total escape distance of the whole cabin is:

$$S = \sum_{i=1}^{4} S_i \quad (3.39)$$

In order to ensure the best security, the total escape distance of the whole cabin should be as short as possible, taking the objective function of security as:

$$\min\{S\} \quad (3.40)$$

The emergency escape distance of narrow-body airliners and regional airliners can be calculated in a similar way.

3.4 Calculation results

In this study, modeFRONTIER software (mF) and Matlab were selected to solve the above model, and the solving process was shown in figure 3.

Figure 3. The solving process of modeFRONTIER

The results can be viewed and analyzed in the Design Space. Pareto solutions are obtained by preliminary screening of calculation results. In order to get the optimal solution, Pareto solutions need to be further screened, which is called decision process.In mF, Multi Criteria Decision Maker (MCDM) can be used to formulate

screening rules, score and rank all schemes, and conduct statistical analysis, so as to screen out the final results that meet the requirements.

4 Verification

In order to verify the validity of the mathematical model proposed in this study, single-channel narrow-body airliners are selected for rationality and feasibility verification. In this study, B737-800 was selected as the benchmarking model, with 162 to 175 seats. The cabin was arranged in two levels, business class seats in 2-2 horizontal layout, and economy class seats in 3-3 horizontal layout. Both business class seats and economy class seats are in the traditional layout, with four adjacent emergency doors arranged in the middle of economy class. The model variation scale is shown in table 4, and the model constant scale is shown in table 5.

4.1 The objective function

The seat should be as comfortable as possible.

$$\text{maxmize } C = (b \cdot x_5 \cdot C_b + d \cdot x_6 \cdot C_d)/(b \cdot x_5 + d \cdot x_6) \quad (4.1)$$

$C_b = x_3/l_0$ 、$C_d = (x_4 - l_{ch,d})/l_{ft}$。

The revenue from a single flight should be as comfortable as possible.

$$\text{maxmize } M = b \cdot x_5 \cdot u_b \cdot P_b + d \cdot x_6 \cdot u_d \cdot P_d \quad (4.2)$$

As for the security, the total escape distance of business class is as follows.

$$S_1 = b \cdot \left(x_5 \cdot L_{p,b} + \frac{x_5(x_5+1)}{2} \cdot x_3\right) \quad (4.3)$$

When the emergency door is set in the middle of economy class, the total escape distance of economy class is as follows.

$$S_2 = d \cdot \left(x_6 \cdot L_{p,d} + \frac{x_6}{2} \cdot \left(\frac{x_6}{2} + 1\right) \cdot x_4\right) \quad (4.4)$$

The total escape distance should be as short as possible.

$$\text{minmize } S = S_1 + S_2 \qquad (4.5)$$

Table 4. Layout optimization model variable scale of B737-800

	length of B1	length of D1	seat row distance of B1	seat row distance of D1	seat rows of B1	seat rows of D1	length of E1	length of E2
variable	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8

Table 5. Layout optimization model constant scale of B737-800

length of cabin	width of cabin	height of cabin	size of kitchen and bathroom	body length	length of foot
L=35000 （1377.95）	W=3750 （147.64）	H=2591 （101.97）	L_0=1016 （40）	l_0=1678 （66.06）	l_{ft}=247 （9.72）
size of baby basket	seat depth of E1	seat width of E1	seat depth of D1	seat width of D1	seat back reclined dimension
l_{ba}=850 （33.46）	l_{chb}=508 （20）	l_{wb}=510 （20）	l_{chd}=431.8 （17）	l_{wd}=440 （17.3）	177.8/127 （7/5）
armrest width of E1	armrest width of D1	attendance of E1	attendance of D1	average fare of E1	average fare of D1
101.6 （4）	50.8 （2）	u_b=100%	u_d=100%	P_b=2000	P_d=1000

4.2 The constraints

According to the cabin layout elements of the relationship, so that:

$$x_1 + x_2 + x_7 + x_8 = L \quad (4.6)$$

$$L_0 + L_{p,1} \le x_7 \le 2L_0 + L_{p,1} \quad (4.7)$$

$$2L_0 + L_{p,2} \le x_8 \le 3L_0 + L_{p,2} \quad (4.8)$$

$$x_3 \cdot x_5 \le x_1 < x_3 \cdot (x_5 + 1) \quad (4.9)$$

$$x_4 \cdot x_6 \le x_2 < x_4 \cdot (x_6 + 1) \quad (4.10)$$

$$x_4 < x_3 \quad (4.11)$$

For economy class, the seat row distance shall include seat depth ($l_{ch,d}$), space for both feet (l_{ft}), and the front seat back reclined dimension ($l_{rh,d}$). In addition, the seat space at the emergency exit shall accommodate the width of the emergency passage, the maximum width of the emergency passage shall not exceed the width of the aisle of the same class. So the seat row distance in economy class shall also be satisfied as follows.

$$l_{ft} + l_{rh,d} + l_{ch,d} \le x_4 \le L_{p,d} + l_{ch,d} \quad (4.12)$$

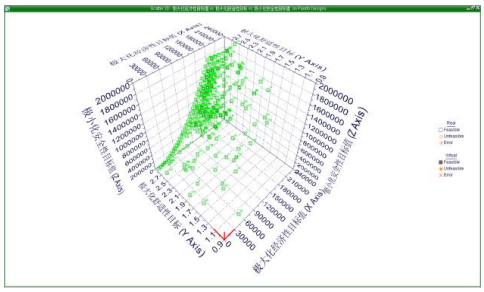
$$\left(l_{ba} + L_{p,min} + 2l_{ch,d}\right) + (x_6 - 2) \cdot x_4 \le x_2 < (x_6 + 1) \cdot x_4 \quad (4.13)$$

$$L_{p,b} = W - b \cdot W_b - (b + 2) \cdot W_{ar,b} \quad (4.14)$$

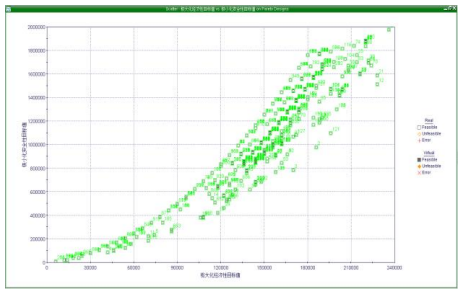
$$L_{p,d} = W - d \cdot l_{w,d} - (d + 2) \cdot W_{ar,d} \quad (4.15)$$

4.3 Solution of the model

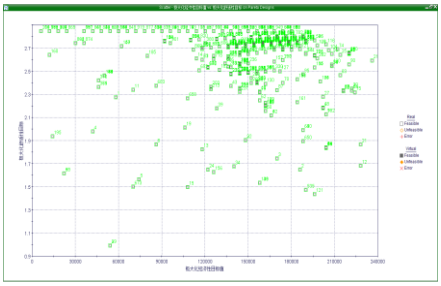
There are a total of 1000 sets of calculation results in the Design Space, and 799 sets of Pareto solutions are screened. In the three-dimensional space composed of three objective functions, or the two-dimensional plane composed of two objective functions, the distribution of Pareto solutions can be intuitively reflected in the figure4.



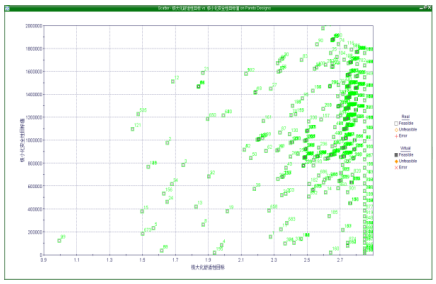
（a）Comfort & Security & Economy



（b）Security & Economy



（c）Comfort & Economy



（d）Security & Comfort

Figure 4. Pareto solution of Multi-objective optimization

The Pareto solutions above were screened by using the Multi Criteria Decision Maker (MCDM) in mF. In this model, X_b, n, X_d, q, min{S}, max{M} and max{C} were defined as Attribute. min{S}, max{M} and max{C} were defined as goal. Genetic algorithms was selected as Algorithm. The effect function and weight were calculated, and the score and ranking of each alternative scheme was obtained. After deleting the duplicates, the top 5% solutions were selected, and statistical analysis and verification were carried out. The results are shown in the table 6.

The seat row distance of B737-800 in business class can be set at about 63in, about 4 to 5 rows. The seat row distance of economy class can be set at about 42in, about 20~23 rows. The cabin class generally ranges from 150 to 180 seats. The total number of seats in the cabin and the number of seats in economy class are basically in line with the mature mainstream schemes of the same class airliners with good

operation in the market, which proves the effectiveness and availability of the cabin layout optimization model proposed in this study.

Table 6. Statistical verification and analysis of cabin layout optimization scheme

	seat rows of E1	seat row distance of E1		seat rows of D1	seat row distance of D1		seats
		mm	in		mm	in	
mode	5.0	1678.000	66	20.0	1084.692	42.7	182.000
	5.0	1626.607		22.5	1084.692		151.000
median			64			42.7	
mean value	4.3	1607.334	63.3	23.1	1077.086	42.4	155.800
standard deviation	1.2	75.302	3.0	3.5	41.738	1.6	23.220

5 Conclusion

In this paper, the optimization method of cabin layout is analyzed, and the factors of cabin seat layout are analyzed from three aspects of comfort, economy and safety. The follow-up research work will be mainly developed from two aspects. On the one hand, the mathematical model is improved to add a variety of seat layout forms, on the other hand, the model is extended to other cabin equipment layout, such as luggage, observation window, PSU, etc.

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Research on the Influence of Music on Information Cognition in the Interactive Interface of Intelligent Sports Equipment

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Abstract: In order to study the influence of music on information cognition in the interactive interface of intelligent sports equipment, this paper outlines obtains the influencing factors based on triangular fuzzy evaluation, designs 2×2×2 three-factor mixed experiment, and arranges them into seven groups (including control group) of music combinations with different attributes, and then uses eye movement test to conduct one-way analysis of variance for the acquisition efficiency and fixation frequency, and explores the cognitive effects of seven groups of music combinations on the information in the interactive interface of intelligent sports equipment. The results show that slow rhythm, no lyrics and foreign songs are the driving factors, while fast rhythm, with lyrics, and Chinese songs are the inhibitory factors. Moreover, the combination of two driving factors can be the best promotion of information cognition; the single inhibitory factor has a slightly inhibitory effect on the information cognition; the combination of two inhibitory factors has the maximum inhibitory effect on the information cognition. Finally, the experimental results are applied to the design of the navigation interface of the e-bike intelligent riding, by embodying the humanized intelligent interface self-adapting, users can promote cognition and improve riding safety no matter what kind of music is played.

Keywords: music; intelligent sports equipment; information cognition; triangular fuzzy evaluation; eye movement

1.Introduction

As a subsidiary element in the interactive interface of intelligent equipment, music is believed to relieve stress, soothe emotions, and express feelings [1-2] for human bodies. Meanwhile, appropriate music information can enhance memory and activate thinking in the human brain [3]. These functions of music make audio gradually become an important means of information transmission. In the literature [4], the influence of no music, light music and heavy music on driver control behavior is studied experimentally and the conclusion is that music affects driver's control behavior, but the influence of light music and heavy music is different. Literature [5] uses 3D simulation driving situation combined with eye movement technology to explore the influence of music rhythm and lyric language familiarity on driving behavior and eye movement law, in addition, the conclusion is that music rhythm and lyric language all have significant influence on driving speed and horizontal search breadth, on the other hand, literature [5] suggests that the driver choose the music with unfamiliar language lyrics and the music rhythm can be determined according to specific situation. Literature [6] explores the influence of no music, Chinese pop music and English pop music on people who are familiar or unfamiliar with Chinese and English word memory. The results show that the memory under the condition of no music is significantly higher than that under the condition of Chinese and English pop music, and the amount of recall of familiar vocabulary under the condition of Chinese pop music is significantly lower than that under the condition of English pop music. Literature [7] studies the influence of music on the instant memories of college students through a large number of experiments, which further affirms that music has a certain connection with cognitive activities of people. Literature [8-10] study the influence of music on the cognition of children, and allows children from different experimental groups to listen to different types of music

and test them. The results show that soft and beautiful music can promote the cognition of children, and on the contrary, music that is too active has a certain impact on the cognition of children. Literature [11-12] carry out the research on how the lyrics attribute of music affects memory. They set up two groups of pure music and non-pure music to compare. The results show that the memory score of the subjects under the influence of pure music is significantly higher than that under the influence of non-pure music. The above research shows that music has a significant impact on individual's memory, attention, cognition, etc. Also it suggests that music with positive influences should be selected when performing behaviors such as memory, driving, and reminiscence, and avoiding play music that has negative influences. However, when people choose to play music, most of them will choose their favorite music instead of choosing the music which is appropriate for the behavior. Since individual's preferences of music are different, there cognition and behavior might be affected by the inhibiting music, or in some cases causing security risks.

The research on intelligent sports equipment is mostly based on wearable equipment. Literature [13] attempts to analyze the current situation of wearable intelligent equipment in the sports and fitness market, and proposes that the current wearable intelligent equipment has become the concept of hot spot in the research and product development. In [14], because wearable intelligent equipment is light in weight, small in size, easy to carry, and the data is also fully reflected on the equipment, the research combines wearable equipment with winter sports to promote the development of winter sports in China. In [15-16], from the interactive relationship among human-equipment-environment, the limitations of the current wearable intelligent sports equipment are analyzed in depth, in addition, the literature finds that the existing intelligent sports products are not friendly enough and lack of feedback mechanism,

leading to problems such as poor user experience, and the literature points out the interaction design principles and design strategies of intelligent sports equipment. Literature [17] proposes a formal method for eliciting and constructing a description of the player's perception of the interaction of sports equipment, and developing a new technique called "structured relationship modeling", which proves that the qualitative technique is effective in arousing human perception and the model that is used to express the discovered connected structural relation is effective, so that the human-equipment interactive relationship between the athletes and the sports equipment, and the interactive relationship between the human-equipment interfaces can be better constructed. Since intelligent sports equipment have only been widely used in recent years, most of the research is limited to wearable devices such as smart bracelets. On the other hand, the research on human-equipment interaction and human-equipment interfaces interaction is not mature. Meanwhile, there are not many literature for reference. However, it has to admit that the development of intelligent sports equipment are very promising.

Regarding the research on information cognition, the design of the interactive interface in the product is fundamentally inseparable from the user's own cognitive ability, sensory acuity, behavioral habits, etc. At the same time, in order to achieve quick access to effective information between the interactive interface and user, reduce maloperation, improve work efficiency, only by combining the cognitive characteristics of users, through the analysis of cognitive bias, cognitive load, emotional cognition and association cognition, summarizing the elements that influence the visual information cognition of users [18] can the human-equipment interactive interface get better improved. Usually, 70% to 80% of external environmental information is obtained by the visual system. Therefore, this paper mainly studies how the music of different

attributes affect the acquisition efficiency and the frequency of fixation when users visualize the visual information of the interface.

In [19], in order to make the interface design better conform to the cognitive behaviors of users, it proposes a general model for comparing visual cognition differences across ages. In [19], with large number of experiments and data analysis, and the feedback of the users' cognitive differences, it provides reference for interface design and development. Literature [20] studies the differences in mobile phone complexity and its impact on information cognition performance of children. The actual or potential application of this research is to improve the cognitive level of interactive interface in electronic equipment and provide usability guidance of children for complex interfaces. Literature [21-22] explore the influence of music on cognitive processing and the relationship between music and cognitive ability, and the two literature conclude that music affects the results of cognitive processing through changes the cognitive processing, and it can improve the cognitive ability to some extent. In this aspect of research, most foreign scholars use the objective indicators of speed and accuracy to evaluate the efficiency of information in the process of user interaction [23-25]. For example, one of the research directions of the art college of Aalto [26] university is to study how to avoid the miss transmission of information in human-equipment interaction based on the current consumption mode [27], so as to improve information cognition and get some relevant influencing factors. However, the above research does not simply explore the changes in the user's information cognitive ability and eye movement indicators under different music types from the interactive interface. Besides, there is no experimental data to support the conclusion.

Research shows that music has a significant impact on human cognition, different types of music have a promoting or inhibiting effect on cognition, especially

for driving behavior. Existing research suggests that users select the type of music that promotes cognition while driving. But individual's preferences are rich, and users are always more inclined to play their favorite songs while driving, regardless of suitability. Therefore, the existing recommendations couldn't achieve the role of promoting awareness and improving driving safety. In the meantime, the level of user cognition of interface information directly affects the quality of the product, and it also affects the safety of drivers under driving behavior. Therefore, combining the broad development prospects of current intelligent sports equipment. This paper explores the influence of single-factor music attribute and different music attribute combinations on the cognitive behaviors and eye movement indexes of information in the interactive interface of intelligent sports equipment. On the one hand, the cognitive behaviors include speed, accuracy and efficiency, on the other hand, the eye movement indexes include fixation frequency and eye movement trajectory. According to the perception of music attribute, a set of intelligent interface is designed to achieve the adaptive matching of interface information and physical information, that is, to meet the users' different preferences for music, and make users have a higher cognitive ability to interface information and play a role of safe driving, no matter what type of music is played.

2 Music attributes that influence information cognition in the interactive interface

2.1 Single factor attribute determination

In order to explore the influence of music on the information cognition in the interactive interface of intelligent sports equipment under the influence of single-factor music attribute and music combinations of different attributes. Firstly it is necessary to objectively determine the music attributes that have a significant influence on

information cognition. The characteristics of music are divided into six attributes, including rhythm, lyric, sound volume, familiarity, language and others. The triangular fuzzy evaluation method is used to objectively determine the experimental influencing factors. There are 4 experts involved in the evaluation decision. The comment set V={the effect is very significant, the influence is quite significant, the influence is significant, the influence is not significant, the influence is quite not significant}, and the fuzzy evaluation of the rhythm attribute index R1 of the criterion layer is done according to formula (1). And then the fuzzy matrix R1=[<78 82 87> <80 85 90> <80 85 90> <88 90 92>] is established. Next, combined with the weight set of the expert evaluation W=[0.3,0.3,0.2,0.2], the comprehensive evaluation of the index, C1=W·R1=[0.3 0.505 0.725], is obtained according to formula (2). Finally, according to formula (3), defuzzification was applied to the triangular fuzzy number C1<s,m,u>, and the result is E(C1)=(0.3+ 2×0.505+0.725)/4= 0.508. Similarly, the defuzzification values of the comprehensive evaluation of other five attribute indexes are: 0.489, 0.32, 0.364, 0.463, 0.183. Therefore, the order of significance of the attribute indexes is rhythm attribute, lyric attribute, language attribute, familiarity, sound volume, and others. As a result, in this experiment, rhythm, lyric and language attributes are selected as the factors that could influence information transmission and information cognition in the process of movement.

$$\tilde{\boldsymbol{R}}_1 = \begin{bmatrix} \tilde{\boldsymbol{r}}_{11} & \cdots & \tilde{\boldsymbol{r}}_{1\boldsymbol{m}} \\ \vdots & \vdots & \vdots \\ \tilde{\boldsymbol{r}}_{\boldsymbol{i}1} & \cdots & \tilde{\boldsymbol{r}}_{\boldsymbol{im}} \end{bmatrix} \quad (1)$$

$$\tilde{C} = W \bullet \tilde{R} = \sum_{i=1}^{n} \left(w_i \otimes \tilde{R}_i \right) \quad (2)$$

$$E\left(\tilde{A}\right) = \left(s + 2m + u\right)/4 \quad (3)$$

2.2 Music combinations of different attributes determination

The experiment randomly selected 20 subjects, 10 males and 10 females respectively,

between 20-35 years old. Their native language is Mandarin Chinese, and they do not know Japanese or Korean, and have never received professional music at all. It designed three-factor mixed experiment of 2 (fast rhythm, slow rhythm)×2 (pure music, music with lyrics)×2 (Chinese song, foreign song), and used Latin squares to arrange for six groups of different attributes of the music combination and a group of no music control, as Table 1 shows. And selected 6 popular music corresponding to different attributes, featuring male singing, strong melody and unfamiliarity. At the same time, it is ensured that each group has a music loop of the corresponding attribute during the experiment. (The average beat of fast-paced music is 126bpm, while the average beat of slow-paced music is 65bpm. In addition, the foreign songs in this experiment are Japanese and Korean language songs.)

The efficiency of information acquisition in the interactive interface of the intelligent sports equipment is the dependent variable one, and the efficiency is calculated by obtaining the speed and the accuracy; the fixation frequency and the movement trajectory of the sight are the dependent variable two, and they are recorded and discriminated by the eye tracker. This experiment studies the influence of music on the information cognition in the interactive interface with pictures and texts of the intelligent sports equipment. The computer screen sets appropriate questions of interface with pictures and texts. The questions are single-choice questions, and each question has three options. The experimental procedures are shown in Figure 1.

Table 1. Different attributes of the music combination

Groups	a1	a2	a3	a4	a5	a6	a7
Attributes	fast rhythm Chinese song	fast rhythm foreign song	slow rhythm Chinese song	slow rhythm foreign song	fast rhythm pure music	slow rhythm pure music	— —

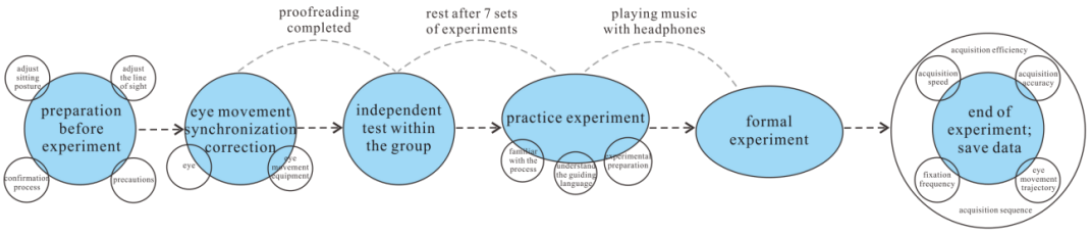

Figure 1. The experimental procedures

3 Research on the impact of music on information cognition

3.1 Acquisition speed study

The experiment uses E-Prime 2.0 software to record the initial data, and SPSS [28] statistical software is applied to process the data, so as to determine whether the attribute has an impact on the acquisition speed or not. Under the single factor condition, the most significant effect on the acquisition speed is the lyric attribute. The acquisition speed without lyrics is higher than that with lyrics; the rhythm attribute has a significant influence on the acquisition speed, and the acquisition speed under slow rhythm is higher than the fast rhythm; the influence of language attribute on the acquisition speed is not significant, however the acquisition speed under the foreign song is higher than the Chinese song; and the presence or absence of music has a significant impact on the acquisition speed. The optimal combination of average acquisition speed under different attribute combinations is a6: the slow rhythm and pure music group; the combination with the lowest acquisition efficiency is a2: the fast rhythm Chinese song group. The analysis of the acquisition speed is shown in Table 2. The average acquisition speed under different attribute combinations is shown in Figure 2.

3.2 Accuracy study

Under the single factor condition, the most significant effect on the accuracy is the

rhythm attribute. The accuracy under slow rhythm is higher than that under fast rhythm; the language attribute has a significant influence on the accuracy, and the accuracy under the foreign song is slightly higher than that under Chinese song; The lyric attribute has no significant effect on the accuracy, but the accuracy under no lyrics condition is slightly higher than that under lyrics; and the presence or absence of music has slightly insignificance on the accuracy. The optimal combination of average accuracy under different attribute combinations is a3: the slow-rhythm Chinese song group; followed by a6: the slow rhythm and pure music group. The analysis of the acquisition of accuracy is shown in Table 3. The average accuracy under different attribute combinations is shown in Figure 2.

Table 2. The analysis of the acquisition speed

		Attributes	df	F	Significant
Acquisition speed		rhythm	35	4.097	.049
		lyric	53	13.014	.001
		language	35	2.655	.112
		No music	125	4.121	.048
		Average	Standard deviation	Average	Standard deviation
Groups	a1	.005332	.001881	a5 .007435	.001590
	a2	.005903	.001755	a6 .007958	.001402
	a3	.006237	.001640	a7 .007329	.001839
	a4	.007509	.002878		

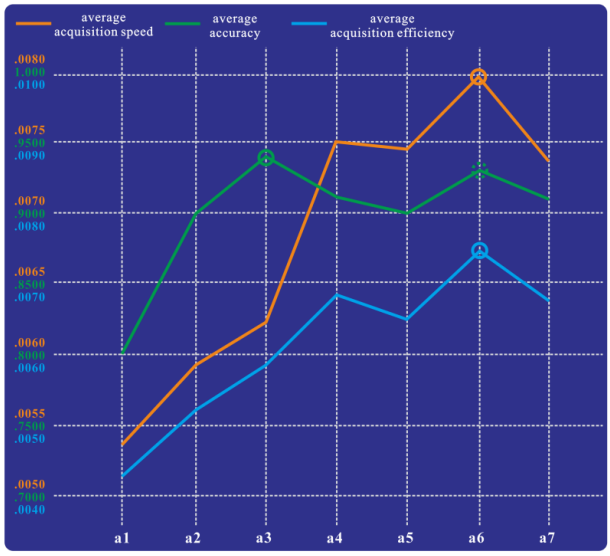

Figure 2. The average under different attribute combinations

Table 3. The analysis of the acquisition of accuracy

	Attributes	df	F	Significant
Acquisition of accuracy	rhythm	35	16.660	.000
	lyric	53	1.545	.220
	language	35	5.276	.028
	No music	125	.650	.080

		Average	Standard deviation		Average	Standard deviation
Groups	a1	.80000	.118818	a5	.90000	.141421
	a2	.90000	.141421	a6	.94444	.114903
	a3	.95556	.109664	a7	.91111	.156765
	a4	.91111	.171117			

3.3 Acquisition efficiency study

Under the single factor condition, the most significant effect on the acquisition efficiency is the lyric attribute. The acquisition efficiency under no lyrics is higher than that under lyrics; the language attribute has a significant effect on the acquisition efficiency, and the acquisition efficiency under the foreign song is higher than that under the Chinese song; the rhythm attribute has a significant impact on the acquisition efficiency, and the acquisition efficiency under slow rhythm is higher than that under fast rhythm; and the presence or absence of music also has a significant impact on the acquisition efficiency. The optimal combination of average acquisition efficiency under different attribute combinations is a3: the slow rhythm and pure music group; the combination with the lowest average acquisition efficiency is a1: the fast rhythm Chinese song group. The analysis of the acquisition efficiency is shown in Table 4. The average acquisition efficiency under different attribute combinations is shown in Figure 2.

3.4 Fixation frequency study

The experiment uses the Tobii eye tracker to determine the acquisition order by recording the fixation frequency and the eye movement trajectory. The fixation frequency is analyzed in the form of a heat map, showing the fixation times and fixation duration of the subjects under the influence of different attribute combinations. The results show that the highest fixation frequency is under the combination of a1: the acquisition efficiency is reduced under the fast rhythm Chinese song combination; the lowest fixation frequency is under the a6 combination, which means the acquisition efficiency would be improved under the slow rhythm and pure music combination. The fixation frequency pupil diameter under the influence of different attribute combinations is shown in Figure 3.

Table 4. The analysis of the acquisition efficiency

		Attributes	df	F	Significant
Acquisition efficiency		rhythm	35	8.459	.006
		lyric	53	15.806	.000
		language	35	12.960	.026
		No music	125	3.647	.046
		Average	Standard deviation	Average	Standard deviation
Groups	a1	.004300	.001680	a5 .006654	.001655
	a2	.005218	.001528	a6 .007515	.001852
	a3	.005958	.001690	a7 .006726	.002160
	a4	.006845	.001231		

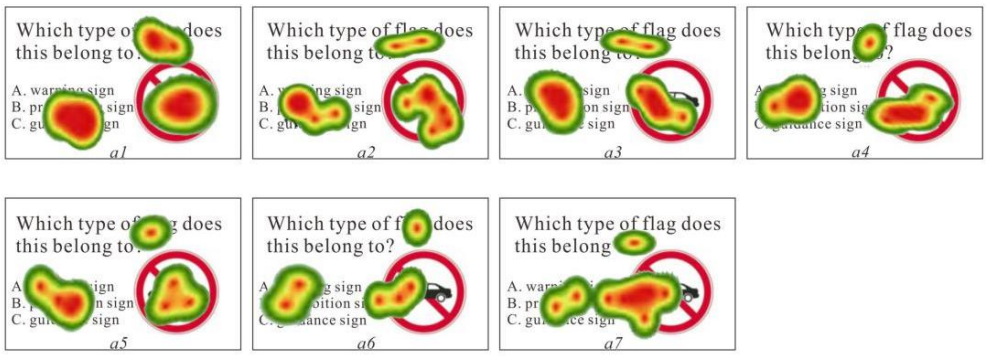

Figure 3. Pupil diameter

The title, text, and picture are used as the information sections, and numbers are respectively marked and statistical data is collected. The results show that the subjects follow the order of reading the title first, and then reading pictures and texts. Additionally, the sight is between the texts and the pictures. There is no linear correlation between the eye movement trajectories, which means that the combination of different attributes does not have significant impact on the eye movement trajectory.

3.5 Research on the influence of different music attributes on information cognition

(1) The study finds that the single factor rhythm attribute has a significant impact on the information cognition. The information cognition under the influence of slow rhythm is higher than that under the influence of fast rhythm; the single factor lyric attribute has a very significant impact on the information cognition, and the degree of cognition under the influence of no lyrics is higher than that under the influence of lyrics; the single factor language attribute has a significant influence on the information cognition, and the cognition degree under the influence of foreign song is higher than that under the influence of Chinese song. Therefore, it can be concluded that slow rhythm, no lyrics and foreign songs are the driving factors; fast rhythm, with lyrics, and Chinese songs are the inhibitory factors. Under the influence of the three attributes of single factor, the eye movement trajectories of the subjects do not change significantly during their reading, and all of the trajectories show the non-linear movement, following the title-image-text order, which indicates that the single factor attribute has no significant effect on the eye movement trajectory.

Table 5. The related effects of music on the combination of graphic and textual information

Groups	Influencing factors				
	Acquisition speed	Acquisition of accuracy	Acquisition efficiency	Fixation frequency	eye movement trajectory
a1	slowest	lowest	lowest（inhibitory）	Compliance with monitoring data	non-linear movement 1.title 2.image 3.text
a2	slow	low	low（inhibitory）		
a3	slower	highest	lower（inhibitory）		
a4	fast	higher	high（promotion）		
a5	faster	lower	medium（inhibitory）		
a6	fastest	high	highest（promotion）		
a7	medium	medium	higher（standard）		

(2) The research shows that the cognition degree of music on the information of interface with pictures and texts under different attribute combinations is a6>a4>a7>a5>a3>a2>a1, which means that the slow rhythm and pure music group and the slow rhythm foreign song group can improve the information cognition degree under the interface, besides, the combination of the two attributes can effectively shorten the information acquisition time, and the acquisition accuracy and efficiency are also guaranteed; the fast rhythm and pure music group, the slow-rhythm Chinese song group, and the fast-rhythm language song group have slightly inhibitory effect on the information cognition under the interface, and the combination of these attributes can slightly increase the information acquisition time and has a certain inhibitory effect on the acquisition accuracy and efficiency; the fast-rhythm Chinese song group has the maximum inhibitory effect on the information cognition under the interface. The combination of this attribute can obviously increase the information acquisition time, and decrease the accuracy and acquisition efficiency. The eye movement trajectories of

the subjects do not change significantly under the combination of different attributes, and all follow the title-picture-text order to do nonlinear movement. The related effects of music on the combination of graphic and textual information under different attribute combinations are shown in Table 5.

4 Design application: take e-bike navigation as an example

4.1 Feasibility verification

The conclusion of this experiment is about to be applied to the research of interface design in the intelligent sports equipment. In order to transform the experimental results into practical applications, the e-bike intelligent riding navigation interface is used as a carrier to build a simulated riding platform. The verification studies are carried out on the basis of the experiment of music's influence on the information cognition in intelligent interactive interface. Verification 1: In the case of the same experimental environment and process, the verification experiment is carried out to conduct analysis. The result shows that the degree of the information cognition of the subjects in the e-bike navigation interface is a6>a4>a7>a5>a3>a2>a1. Although the simulation of cycling will result in a slight decrease in acquisition efficiency, the verification results are basically consistent with the experimental results. Verification 2: On the basis of verification 1 with other conditions remain unchanged, and the physical information in the e-bike navigation interface is adjusted as follows: under the a6 , a4, a7 attributes, the size of navigation interface is 9 inches, wherein the text information is Times New Roman 11pt, the word space is 2pt, the image size matches the text, the image space is 1.5 lines, in addition, the standard size is specified; under the a5, a3, a2 attributes, the main information of the interface is enlarged by 0.4 times; under the a1 attribute, the main information of the interface is enlarged by 0.6 times. The analysis shows that after

the main information of the interface is enlarged, the information cognition degree under the attributes of a5, a3, a2, and a1 can be improved, and except for the a1 attribute, the information cognition degree under other attributes is greater than the a7 control group; under the influence of the a6, a4, and a7 attributes, the information cognition degree is consistent with the results of verification 1. The verification results are shown in Table 6.

Table 6. The verification results

Groups	a6	a4	a7	a5	a3	a2	a1
Acquisition efficiency	.007413	.006830	.006708	.006812	.006720	.006714	.006708
conclusion	consistent	consistent	consistent (control group)	improve >a7	improve > a7	improve > a7	improve = a7

4.2 Application of e-bike navigation design

Therefore, during the riding and playing different music, in order to ensure the cognitive function of the information in the e-bike navigation interface, the system will automatically adjust the interface information by recognizing the music attribute. So that no matter what kind of music is played, the information in the interactive interface of the intelligent sports device has faster acquisition speed and higher acquisition efficiency, so as to reduce the maloperation and improve the safety during the riding process.

By synthesized the experimental results, it can be seen that based on no music, when playing slow rhythm and pure music, and slow rhythm foreign songs, the information cognition can be improved a lot, which means that in this kind of attribute

combination, the information in the interactive interface of intelligent sports equipment is of standard size; when playing the fast rhythm and pure music, slow rhythm Chinese songs, fast-rhythm foreign songs, the information cognition will be slightly inhibited, which means that under this combination of attributes, the main information of the interface is enlarged by 0.4 times, and the related information is reduced by 0.6 times. Moreover, in the case of crossing the road, there are three safety warning lights flashes and three beeps; when playing the fast rhythm Chinese songs, the information cognition will be inhibited to the maximum degree, which means that under the combination of these attributes, the main information in the intelligent interactive interface is magnified by 0.6 times, and the related information is reduced by 0.4 times. Additionally, the safety warning light continues to flash under the condition of crossing the road, and after the warning tone sounds three times, the road voice broadcasts start. Different sizes of intelligent interactive interface are shown in Figure 4.

(1) standard size (2) slightly inhibited size (3) maximum inhibited size

Figure 4. Different sizes of intelligent interactive interface

5 Conclusion

This experiment takes cognitive psychology as the theoretical basis. Based on the triangular fuzzy evaluation, the three music attributes influencing the experiment are obtained, and the experimental independent variables are determined. Through the experiment, the information acquisition efficiency and order are used as indexes to

explore the relative influence on the information cognition under the three major music attributes of rhythm, lyrics and language, and under different attribute combinations. The results show that slow rhythm, no lyrics and foreign songs are the driving factors; fast rhythm, with lyrics, and Chinese songs are the inhibitory factors. Moreover, the combination of two driving factors can be the best promotion of information cognition; the single inhibitory factor has a slightly inhibitory effect on the information cognition; the combination of two inhibitory factors has the maximum inhibitory effect on the information cognition.

Combined with the existing research, this research is of great significance in embodying humanized design. It is different from recommending the selection of appropriate music and changing the user's own preferences. This study meets the user's demand for playing favorite music, and combines the experimental results to design through the interface self-adaptation, which enables users to quickly obtain effective information when listening to any kind of music, and the security can be improved. The results of the experiment can provide relevant design basis for the design of interaction interface of the e-bike navigation and similar intelligent sports equipment, especially for the operating interface of intelligent outdoor sports equipment. Meanwhile this experimental conclusions in this study can be used as a basis to realize the design and development of related software in the future. For example, using Visual Basic software for program development. According to the different influences of different attributes of music on the information cognition in the interactive interface of intelligent sports equipment, a system software is developed, which can realize the adaptive matching of interface information and physical information according to the perception of music attributes. Adaptive matching improves user cognition during user interaction with the interactive interface, thereby improving the efficiency of information transfer.

However, this experiment also has some shortcomings. First of all, the feedback sound in the interactive interface of intelligent sports equipment has a significant impact on the information cognition in the process of human-equipment interaction. However, due to the lack of experimental equipment platform, this experiment only researches the relevant influence of music attributes, in addition, does not do the feedback sound research. Secondly, in the application verification, this experiment does not do much research on the specific amplification of physical information in the interface. In the end, the analysis process of the experimental data will have accidental error. Therefore, the results in this experiment are general conclusions under the experimental environment, which can lay a certain foundation for the research of related topics.

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Research on Design Strategy of Playful Products for Elderly Based on Case Analysis

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Abstract: Background: it is true that aging populations are increasing. Between 2000 and 2050, the proportion of the world's populations over 60 years will double from about 11 percent to 22 percent. And aging also brings many challenges to the development of society and the daily life of the elderly. Studies have shown that, to some extent, playful products such as special designed toys and smartphone or computer games are useful for the elderly to maintain health and to cope with the challenges of aging. However, the quality and quantity of playful products available to the elderly on the market are not very ideal. Therefore, this paper summarizes the basic design insights of toys and games through the analysis of some typical tangible toys (such as traditional ball toys, card games and so on) and digital games (such as smartphone games, computer games and virtual reality games, etc.) on the market. In combination with the characteristics of the elderly, a number of design strategies are proposed to guide designers in quickly collect insights in the design process of toys and games for the elderly which may lead positive impacts to their healthy ageing.

Methods: this paper mainly uses case analysis and comparative analysis methods. A sample of toys and games on the market was collected by the researchers from a variety of website. Websites where typical toys and games were found were Pinterest (design inspiration website), App store, Google Play and some other

online platform with a screening method. Finally, 30 typical representative cases were selected to the further case analysis.

Results: combined with the five elements of interaction design - person, behaviour, purpose, media and context which proposed by Professor Xin Xiangyang, the cases collected are analysed and summarized, and five design insights are proposed with several examples.

Conclusion: there is no doubt that aging will bring many disadvantage factors to the elderly's daily life. At the same time, different elderly people will show different living conditions in their later years. There are many design elements which may influence the elderly interact with a designed toys or games that are worth considering. Therefore, we promote a model with three dimensions which may help designers design a more suitable game or toy for the target elderly: personal capabilities (Physical, cognitive capability) [Restorative or Compensatory], social relationships [Connectedness and Autonomy], computer skills [Hard interaction (Online) and Soft interaction (Offline)]. The model emphasizes that toys and games can be used to balance certain extreme characteristics of the elderly and help them achieve a healthier lifestyle.

Keywords: design strategy; playful products; elderly; healthy aging; case analysis

1 Introduction

Aging challenge

Challenge of aging society

The absolute number of people aged 60 years and over is expected to increase from 605 million to 2 billion over the same period. Today, for the first time in history, most people can expect to live into their 60s and beyond. Longer lives present many opportunities, and makes a strong case that appropriate social investment can create a "third demographic dividend" for society.

Some researches pointed out the extent of the opportunities that arise from increased longevity will depend heavily on one key factor: health. If people are experiencing these extra years of life with declines in capacity and disabling environments, the implications for older people and for society are much more negative. Population aging generates many challenges and sparks concerns about the pace of future economic growth, the operation and financial integrity of healthcare and pension systems, and the well-being of the elderly and their families.

Challenge of elderly

In addition to the vary challenges that aging brings to society, such as the needs of healthcare policy, the potential economic pressure, and the prospect of human wellbeing and so on, challenges posed by aging to individuals are also diversity because of the heterogeneity of elderly, most of them own different social relationships, healthy status and living standard, what's more, their internal character such as personality, lifestyle and cultural background which may lead to a very different living challenges to the old individuals. Ageing is a multidimensional process of change in the physical, mental, and social domains, leading to functional decline Research shows many older adults will

live with, rather than die from, the disablement that accompanies chronic diseases. In addition, dementia and depression are the most common psychiatric syndromes in older age, which can seriously affect the quality of life of the elderly and their families. What's more, social support networks may change when people retire and have less social contact through work. This is often followed by losing the ability to drive, further limiting opportunities for socialization. Disruptions to social networks often continue due to the death of a spouse and close life-long friends, such disruptions to social support networks may negatively affect physical, cognitive, and mental well-being.

Benefits of playful product for elderly

Rowe, J. W. and Kahn, R. L. defined successful aging as including three main components: low probability of disease and disease-related disability, high cognitive and physical functional capacity, and active engagement with life. But how can we help the old adults get successful and healthy aging and maintain their quality of life when they face functional, physical and social challenges of ageing? Although in the common sense of most people, play is a free and voluntary activity that we do for no other purpose than the play and enjoyment. Nevertheless, playing may lead to important collateral effects. Some studies pointed out that these collateral effects of play for the elderly are shown to be significant and important, especially in the area of health, it can be educational achievements, motor skill enhancement, cognitive and physical rehabilitation Research has shown that playing games can have positive effects on the emotional and physical well-being of elderly persons, and can motivate them to maintain a basic level of activity. Play is suitable for health promotion as it intrinsically can motivate to activity by its open-ended and continuously formed (e.g., curiosity) nature, and its ability to evolve in social interaction, afforded and mediated by situational and technological conditions. Computer training, memory tapes, and

Nintendo games are also marketed to the lay public with claims of that games and toys can enhance cognition based on the theory of “use it or lose it”.

Market situation of playful products for elderly

In Germany, some of the companies which was a traditional manufacturers of children's toys, faced with the crisis of the industry, caused in particular, by the reduced birth rate, manufacturers have paid attention to older consumers. During research it was found that older people a lot and enjoy playing Board games in the company of 2-4 people.
Especially popular among the new target audience are logical and team games: puzzles, bingo, dominoes, assembly models, creative kits, etc. that have traditionally focused on children. Eventually the adults, who buy toys, are regarded as the most promising group, which is especially relevant in the context of an ageing population.

While movies and fashion increasingly address age diversity, we still do not see widespread up-take of inclusive design for consumer goods or advanced aesthetics in assistive technology. Especially for the playful products of elderly, our research shows that the playful products of the elderly have a very low market share in the entire playful products market.

By entering keywords "toys and games ", "toys and games for elderly (or old adults and seniors)" and "toys and games for children (or kids and babies)" on several major e-commerce websites, a summary of the search results is presented in Table1.

The search generated over 249419 toys and games on e-commerce websites, compared to the high amounts of toys & games for children, kids or babies, few toys and games were special designed for elderly people particularly. Of course, the results including some duplicated products due to parallel searches. In addition, as far as the toys and games related to elderly retrieved on the website are concerned, there are a

large number of products that are not intended to be related to the elderly among the search products obtained by inputting keywords such as "toys and games for elderly, old adults or seniors", therefore, the real amounts of toys and games related to the elderly should be lower.

Table 1 Summary of searches

Search strategy	Amazon	eBay	Alibaba
Toys & games	over 100,000 results	67,275 results	172144 results
Toys & games for children, kids or babies	over 70,000 results for children, and over 70,000 results for kids, and over 50,000 results for babies	19,190 results for children, and over 19,239 results for kids, and over 1,475 results for babies	38,599 results for children, and over 94,478 results for kids, and over 17,382 results for babies
Toys & games for elderly, old adults or seniors	over 1,000 results for elderly, and over 30,000 results for old adults, and over 2,000 results for seniors	3 results for elderly, and over 2 results for old adults, and 7 results for seniors	92 results for elderly, and 462 results for old adults, and 95 results for seniors

What's more, when we searched games on the App Store, we found that there was an independent children's game classification module, but lack of a special module for elderly. And the game classification details on App Store like the below Figure 1.

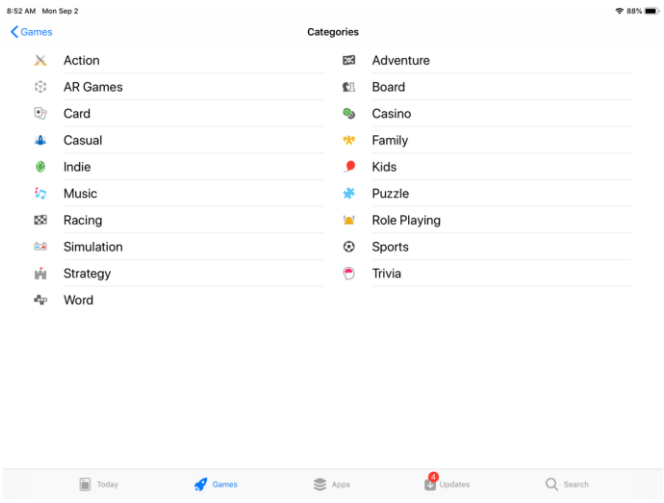


Figure 1 The categories of games on App Store

This paper does not list detailed researches to point out the specific reasons why there are so few toys and games designed for the elderly in the market, while we can

guess perhaps because we generally believe that old people have less motivation to play toys and games, and if they really want to play, as older adults they should be able to enjoy most games designed for children and adults.

Actually, elderly people have stronger motivations to play toys and games than we generally believe, as the author mentioned before, previous research pointed out the potential needs of elderly for the toys and games market, what's more, most of them show a strong potential consumption ability. And what is worthy to consider is that some of their motivations could be different from those of children and young adults. A number of studies showed that elderly people have problems in using many of the games currently available on the market. Their difficulties include problems in getting familiar with the game technology and embarrassment about using the tools designed for the game. Furthermore, certain games were considered too demanding or even risky for elderly people. Yet, their special needs have been largely ignored, and few toys and games have been particularly designed for the elderly population. To design toys and games for elderly, designers need to be aware of the unique motivations of elderly, their capabilities, technological skills and ideal level of challenges, and also corresponding particularities in design requirements. Design for old adults itself requires the consideration of a range of design problems, which may be related to highly personal matters.

Gap & Aim

As the author mentioned earlier, aging lead to vary challenges for both society and the elderly, previous researches have confirmed that toys and games can help older people and society cope with the challenges of aging and promote healthy aging. Although many efforts have been made to optimizes the quality of life of the elderly by

advocating design issues such as inclusive design and accessible design, less attention has been paid to the design strategy of playful products for elderly, the quality and quantity of toys and games for the elderly are not optimistic on the market. With combination of the characteristics of the elderly, a number of design strategies are proposed through the case analysis which may be a guideline for designers in quickly form insights in the process of design toys and games for the elderly.

Research Questions

And this paper will focus on the following questions: 1. What are the potential relationships between the typical toys and games (included the tangible toys and digital games) on the market and how to form observations and design insights based on these potential relationships in the process of design these kind of toys and games? 2. What are the main characteristics of old adults and how to contribute these characteristics into the design process of games and toys for elderly?

2 Method

Cases collection

A sample of toys and games on the market was collected by the researchers from a variety of website. Websites where typical toys and games were select from Pinterest (design inspiration website), App store and Google Play, what's more, in the process of case screening, some cases obtained through other channels (such as early cases accumulated by researchers, cases recommended by other designers or design cases mentioned in some published papers) that meet the inclusion criteria will also be included. The search strategy included the following terms: ''toys'' OR ''games''. To ensure that cases are more easily identified, some cases that seem complicated and

difficult to understand are also excluded. The clearly criteria and steps of cases filtering is presented in the following Figure 2.

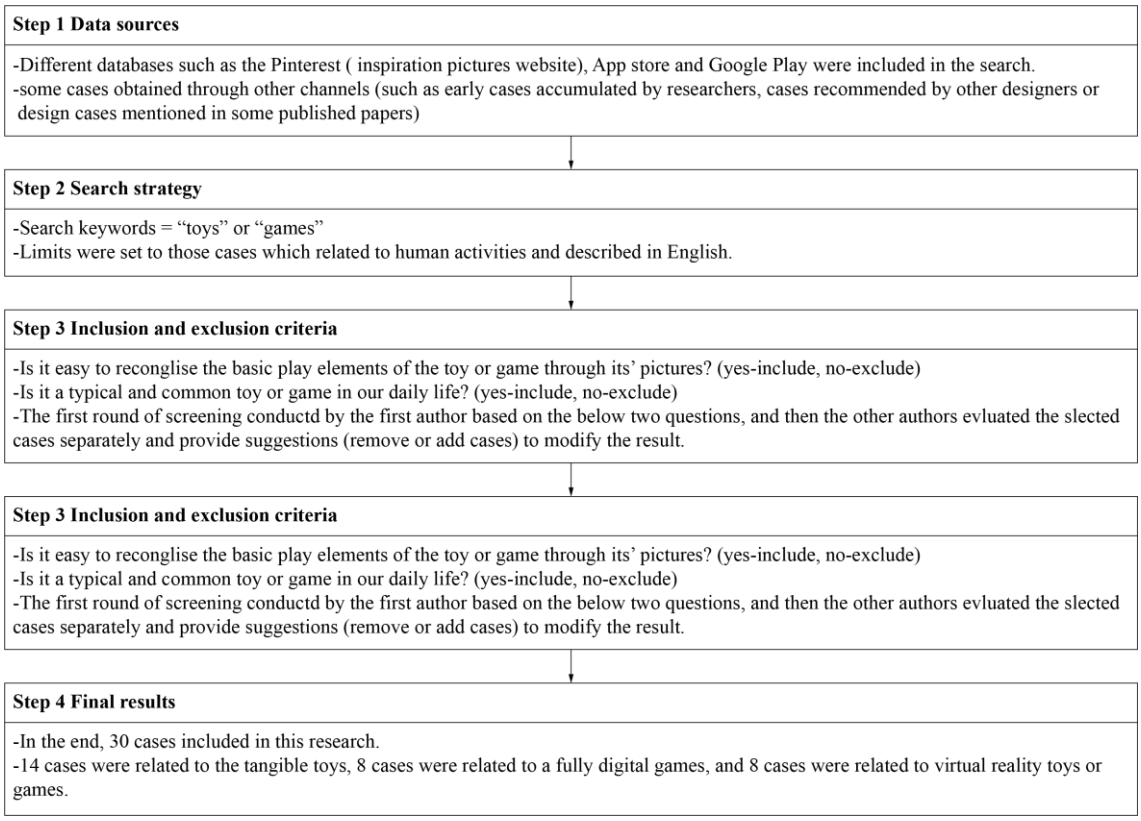


Figure 2 The criteria and steps of cases filtering

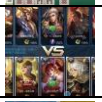
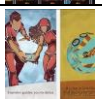
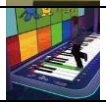
Finally, 30 typical representative cases were selected to the further analysis. The source of the cases followed the application of triangulation, to be sure, the application of triangulation (multiple sources of data) will go a long way towards enhancing the reliability of results and the attainment of data saturation.

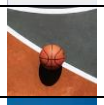
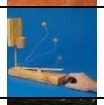
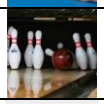
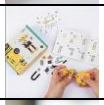
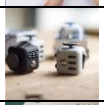
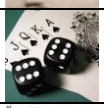
In the process of collecting cases, when we try to keep expanded the sample size, we found that the newly added games and toys had some degree of overlap with some of the previous toys. Despite the numerous forms and functions of toys and games, most of them have similar characteristics, which are based on factors such as puzzles, balls, and cards. As pointed out in previous researches, there is no one-size- fits-all method to reach data saturation; moreover, more is not necessarily better than less and vice versa.

Data saturation is reached when there is enough information to replicate the study, when the ability to obtain additional new information has been attained.

This resulted in a total of 30 toys and games in the sample. While this sampling process is not strictly random, it is a convenience sample, we have no reason to suspect that it resulted in any bias. The results of the 30 cases are summarized in Table 2.

Table 2 Characteristics of cases.

Numbers	Images	Names	Elements	Target users	Number of players	Capability Requirements	Media	Sources
1		*Fit Brains Trainer*	Award-winning brain training & fitness app, education	no strict limits	Play alone	High cognitive ability	Online	Google Play
2		*Monument Valley*	Indie puzzle game	Almost young people and adults, no strict limits	Play alone	High cognitive ability	Online	Google Play
3		*Cookie crush*	Soft games - Mobile Entertainment Services, Puzzle	no strict limits	Play alone	General cognitive ability	Online	Google Play
4		*Brain wars*	Time Concentration Battling App (Puzzles Crosswords, Sudoku, and other brain teasers)	no strict limits	Compete with friends	High cognitive ability	Online	Google Play
5		*Jump Jump*	Puzzle game	no strict limits	Play alone or play with friends	General cognitive ability	Online	Google Play
6		*Snake Off*	Action game	no strict limits	Compete with friends	General cognitive ability	Online	Google Play
7		*Mahjong Lianliankan*	Puzzle game	Almost adults, no strict limits	Compete with friends	High cognitive ability	Online	App Store
8		*Arena of Valor*	Action game (multiplayer online battle arena (MOBA))	Almost young people and adults, no strict limits	Play with friends & Compete with others	High cognitive ability	Online	Google Play
9		*Bounden*	Casual, music & video (a online game guide to dance)	no strict limits	Play with friends	General cognitive ability & High physical capability	From online to offline	Google Play
10		*Pokemon Go*	Adventure game (A online game guide you explore and discover virtual Pok émon anywhere)	Almost young people, no strict limits	Play alone	General cognitive ability & general physical capability	Virtual Reality	Google Play
11		*Virtual football*	Virtual football game	no strict limits	Compete with friends	General cognitive ability & High physical capability	Virtual Reality	Pinterest
12		*Foot electronic piano*	Foot electronic piano	no strict limits	Play alone	High cognitive ability & general physical capability	Virtual Reality	Pinterest
13		*LEGO Mindstorms*	LEGO System A/S, tools, creativity game (Create and command robots that do what you want)	Almost child and young people, no strict limits	Play alone or play with friends	High cognitive ability & general physical capability	Virtual Reality	Google Play

14		*Yeehaw Wand*	3D draw-and-print system	Almost adults, no strict limits	Play alone	High cognitive ability	Virtual Reality	Other channels (Kickstarter official website)
15		*Osmo*	Online tangible play	Almost child, no strict limits	Play alone	High cognitive ability	Virtual Reality	Other channels (Osmo official website)
16		*PARO Therapeutic Robot*	Smart robot	Old adults	Play alone	No limits	Artificial intelligence	Other channels (Parorobots official website)
17		*Rubik's Cube*	Puzzle	no strict limits	Play alone	High cognitive ability	Offline	Pinterest
18		*Building blocks*	Puzzle, creative	Almost child and young people, no strict limits	Play alone	General cognitive ability	Offline	Pinterest
19		*Basketball*	Ball game	Almost young people and adults, no strict limits	Play with friends & Compete with friends	General cognitive ability & High physical capability	Offline	Pinterest
20		*Board basketball*	Board game	no strict limits	Play alone or play with friends	No limits	Offline	Pinterest
21		*Bowling*	Ball game	Almost adults and young people, no strict limits	Play alone or play with friends	General cognitive ability & High physical capability	Offline	Pinterest
22		*Board bowling*	Board game	no strict limits	Play alone or play with friends	No limits	Offline	Pinterest
23		*Assembling robot*	Assembling game	Almost child and young people, no strict limits	Play alone	General cognitive ability	Offline	Pinterest
24		*Fidget cube*	Finger toy	Almost adults, no strict limits	Play alone	No limits	Offline	Pinterest
25		*Dice war*	Dice war, board game	Almost adults, no strict limits	Compete with friends	General cognitive ability	Offline	Pinterest
26		*Balancer*	Balancer	Almost child and young people, no strict limits	Play with friends	High physical capability	Offline	Pinterest
27		*Mahjong*	Board game, card game	Almost adults, no strict limits	Compete with friends	High cognitive ability	Offline	Pinterest
28		*Monopoly*	Board game	Almost child and young people, no strict limits	Compete with friends	High cognitive ability	Offline	Pinterest
29		*Bridge card*	Board game	Almost adults, no strict limits	Play with friends & Compete with friends	High cognitive ability	Offline	Pinterest
30		*Bingo*	Board game	Almost old adults, no strict limits	Compete with friends	General cognitive ability	Offline	Pinterest

From the cases the author collected, we can observe that although most of the

playful products are different in forms and contents, to some extent, some of them have a certain similarity and relevance, such as Mahjong and Mahjong Lianliankan own the similar forms and play rules despite one of them is online game and another is tangible board game. Of course, there are also some examples show a huge different features despite their similar forms, such as Dice war and Fidget cube, which present very different functions and paly rules. There is no doubt that it is worthy to make a deep analysis of the potential relationships between different playful products.

Cases analysis

From the above table, the author makes a simple classification of the categories of games and toys based on their functions or goals, most of the games and toys are consist of creative, socialize, educational, self-entertainment and fitness playful products which may help the players create innovations, communicate with others better, learn more new knowledges, or just kill their times and keep a healthy body.

Figure 3 The categories of playful products

Play is the paragon of enjoyable, intrinsically motivated activity, associated with a wide range of positive effects on experience, motivation, social interaction, learning, and wellbeing. It has also been shown that older adults enjoy playing games, but interaction challenges have to be addressed.

Therefore, combined with the five elements of interaction design - person, behaviour, purpose, media and context, the game cases collected are analysed and summarized, and the design insights of five types of games and toys are obtained, the results of the design insights are summarized in Figure 4.

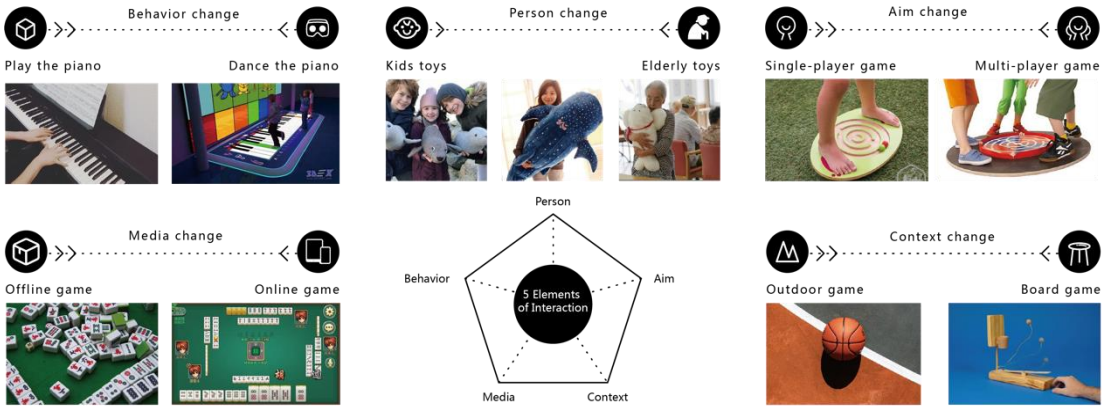


Figure 4 Design insights of games and toys

As you can see from the above figure, combined with case analysis, five interactive design ideas for games and toys are proposed. The first case focuses on the introduction of new designs through the transformation of interaction behaviour, in addition to playing the piano by hand, you can play the music with your foot on the piano. The second case emphasizes the transformation of users of targeted games or toys, some product design concepts may be designed for children in the beginning, such as toy puppets, after redefining and redesigning, these products can also serve the elderly. The third case emphasizes the change of the interaction design goal, by adding social attributes into some games, such as turning some single-player games into multi-player games, you can also create some new play rules for the old games, and bring some new fun to the player. What's more, in the process of designing the game, we can also think about designing new games by changing the media of the games or toys, such as extract the play rules of traditional Mahjong and redesign it into an online game, therefore, you can use this software with any friends at any time and place to enjoy the fun of playing Mahjong. Of course, for game and toy design, the context of play is also very important, by changing the context, such as extracting the elements and rules of the basketball, and then redesign it as a board game, which may help some disable players

enjoy the fun of basketball.

3 Conclusion

Interaction paradigms and game mechanics are often granted a higher priority than the consideration of individual player abilities, which is appropriate when designing for younger audiences but may not suffice when designing for older adults.

Age-related changes and impairments processes are likely to have an impact on older adults' ability to engage in the interaction in the game. Common age-related changes include decreases in sensory acuity and effects on memory and attention. Advanced age leads to the reduction of muscle mass, which causes decrements in strength and stamina, decrements in balance and gait are common among older adults, and the risk of falls increases, which needs to be accounted for when designing movement-based interaction games. As the author mentioned earlier, retirement, loss of friends, physical and cognitive decline are all potential factors for social isolation in the elderly, and maintaining good social relationships is critical to the healthy ageing of old adults. Social relationship of elderly should be considered when designing social-based interaction games. Due to the different levels of education, their capacity to use standard approaches to human-computer interaction are different. Therefore, the technological or computer skills of elderly is a key factor which may influence the media of the games and toys.

Within game studies, there is an increasing acknowledgement that any definition of "games" has to go beyond properties of the game artefact to include these situated, socially constructed meanings. Physical capability, cognitive ability, social relationship and computer skills, all of those factors have to be considered when designing games or toys for older adults. What's more, it is true that changes in physical and social networks occur with aging, but there is greater recognition that older people are not a

homogeneous group. Are the target elderly more dependent on others or too autistic? Can they train their bodies to become more robust or some of them have been lost their mobility? Are they proficient in using electronic products or against the use of such smart products?

There are many factors that will influence the elderly interact with a designed game or toy, therefore, we promote a model (Figure 5) with three dimensions which may help designers design a more suitable game or toy for the target elderly: personal capabilities (Physical, cognitive capability) [Restorative or Compensatory], social relationships [Connectedness and Autonomy], computer skills [Hard interaction (Online) and Soft interaction (Offline)]. The model emphasizes that games can be used to balance certain extreme characteristics of the elderly and help them achieve a healthier lifestyle.

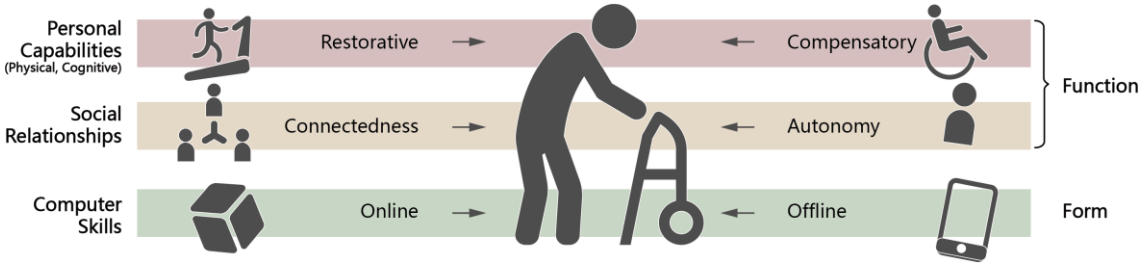


Figure 5 Playful design strategy model for elderly

As below shows, the author has given some examples (Figure 6) of how to apply the design strategies mentioned above in the process of designing games for old adults.

For the first one, in the dimension of Personal capabilities, for the elderly whom with a good physical or cognitive capability, it would be better to choose the restorative design strategy to design a game or toy for them which may help them recover and enhance their physical or cognitive ability. Such as redesign entertainment games (which may have no strict requirements to the players physical capability) like Jump

Jump by learning from full-body games (which have a certain degree of demand of the players physical capability) like Bounden. On the contrast, for those elderly people who have limited mobility, physical disabilities or cognitive impairments, compensatory design strategy would be a better choice, by actively reducing the requirements of physical or cognitive ability of games or toys, such as turning Bowling into a board game, which may make up for their lack of physical or cognitive ability, so that they can also enjoy this kind of game.

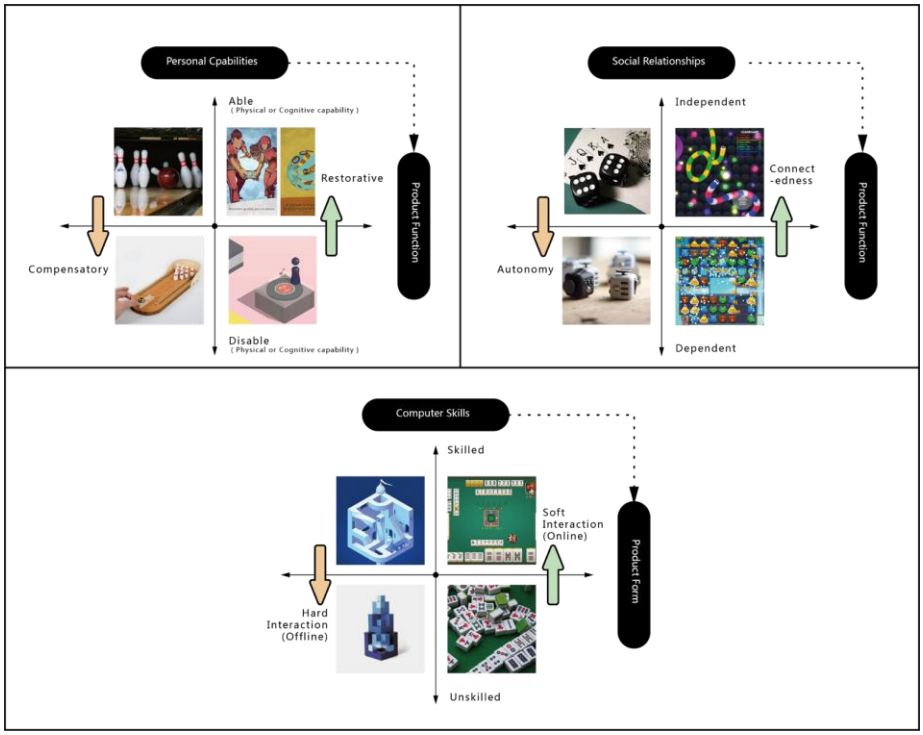


Figure 6 Playful design strategies for elderly

What's more, in the dimension of social relationships, on the one hand, we encourage using connectedness design strategy to help those elderly people who are facing social isolation design games or toys with strong social attributes , which may help them build intimate social relationships and good for their healthy, as you can see, compared to single-player game Cookie Crush, multi-player game Snake Off is more conducive to helping players maintain social relationships. On the other hand, for those who are overly dependent on playing with other friends and losing their ability to be

alone, we also need to properly apply autonomy design strategies to design a game or toy which may help them learn how to get along with themselves. Dice War may be more suitable to play with friends, but Fidget Cube can help the elderly kill time when they stay alone.

Of course, computer skills is also a key factor which may influence design trends of games or toys for elderly. In general, for those old adults who are good at using electronic products, It would be better redesign those traditional offline games into online games, so that they can play those games with anyone at any time and place, turning the traditional Mahjong game into online Mahjong Lianliankan game with the similar play rules is a good design case. It is undeniable that there are a large number of elderly who do not use electronic products or do not like to use electronic products in our lives, therefore, it would be better to help them design games through hard interaction design strategies. Sometimes, they may also interested in the online games or news, but they do not know how to play it or they just refuse to use it, if we try to extract some elements of online games and turn those elements into physical games or toys, to some extent, may help them reduce their feeling of loss, or satisfy their curiosity. After redesigning the video game Monument Valley, which was previously popular on the website, can also become a fun physical game Building Blocks. And the following Figure 7 show the potential combination of the six strategies we mentioned before, we can choose any one, two or three of them except the opposite two strategies together.

4 Discussion

Indeed, there are some limitations in this paper, first of all, we encountered some challenges in screening the cases. Even though we used different databases to collect cases and hope to ensure that the playful products cases we collected were not biased,

but it can't be discharged that we may did not rule out all the typical cases and there may still be some typical cases that were not discovered by us. However, it is worth noting that the purpose of this study is obtain some new design insights by the comparative analysis of some typical playful product cases, and combine this design insights with the typical characteristics of the elderly which the previous study mentioned, then came up with several design strategies (not all of the design strategies) which may help the designers form design insights quickly during the process of design games or toys for elderly. Therefore, even if some typical cases are omitted, it will not have much impacts on our design research. Due to the limitations of the data, our final design strategies may not meet all the design requirements during the design process. For some special cases, we may still need guidance from other design strategies. Of course, in the future, we will still improve the quality of screening method of the case, in order to extend the quantity of cases sample, and then propose new strategy to enrich the design strategies.

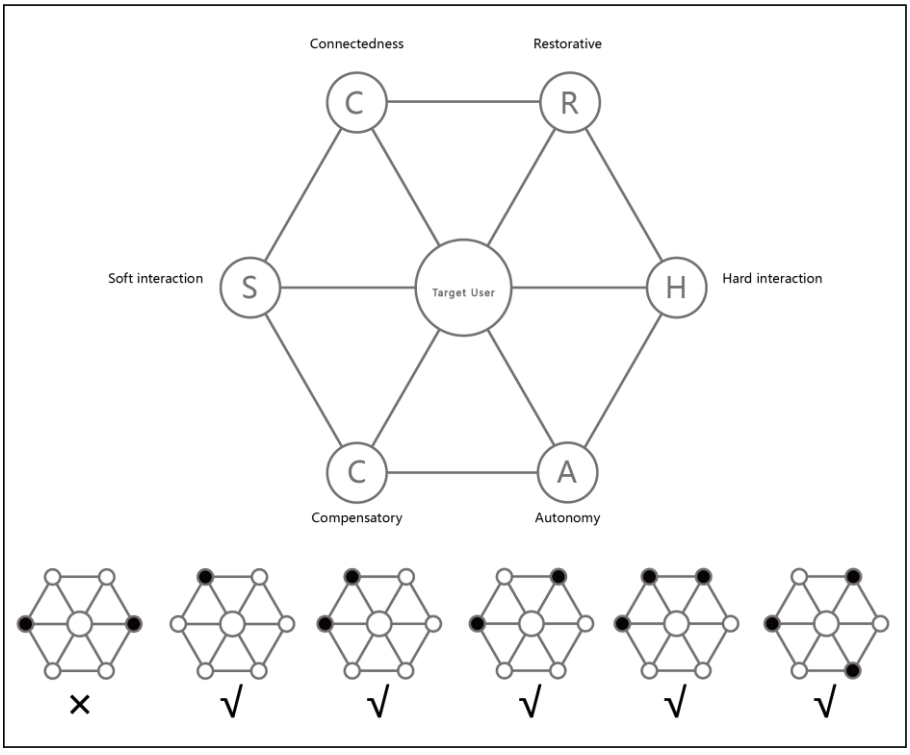


Figure 7 Combination of several design strategies

By the way, although there are some other categories of playful products that are good for the health of the elderly, the playful products we mentioned in this paper mainly related to games or toys. Maybe games and toys sound more like entertainment products, but the important collateral effects of games and toys should not be ignored, and those additional values are also worth researching.

In conclusion, in spite of limitation this paper came up with the design strategies that which may help the designers form design insights quickly during the process of design games or toys for elderly. Of course, in order to verify the effectiveness of these design strategies, we designed a double-blind experiment to verify the impact of these design strategies on the designer's design insights when they design games of toys for elderly. Because of the limitations of space and subject, we did not describe the relevant experimental content in this paper, but it is still worth mentioning that, to some extent, our experimental results prove the effectiveness of the design strategies. And we will describe the detailed experimental process and results in the next paper.

5 Acknowledgment

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Collect Your Happiness: A Case Study of Using Positive Psychology Principles in Technology Design

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Abstract: More and more of our daily activities depend on smartphones and applications. Thus, an increasing number of studies are interested in whether interactive applications can be used to improve the happiness of individuals. This paper presents an application called Collect Your Happiness that is based on some positive psychology principles. It can not only enhance people's happiness by collecting their daily happy moments but provide small tasks to improve their happiness levels. A cross-cultural measurement between the Chinese and Dutch was conducted to evaluate the efficacy of this intervention by SHS, SWLS, PGWBI, and MAAS. Also, collected moments were coded based on Seligman's PERMA model to analyze the cultural differences. Results show that CYH can help people from both countries improve their happiness. The Chinese tended to find their happiness in relationships with their friends and family. However, the Dutch tended to search for meaning and engagement in their lives.

Keywords: positive psychology; collect your happiness (CYH); cross-culture; PERMA

1 Introduction

Most people spend much time in the smartphones and applications, so smartphones play an important role in maintaining and promoting happiness for us. For instance, people increasingly collect personal daily activities and often share them through smartphones. However, a question arises as to whether the use of such applications has a positive influence on our happiness?

In the last decade, the growing interest in HCI among technology professionals is a larger emerging public concern for how our digital experience is impacting our happiness. Researchers and designers are gradually leaving behind task-oriented perspective and using technology to improve people's happiness. Rafael Calvo and Dorian Peters refer to the design and technology to support happiness and human potential as positive computing (R. Calvo & D. Peters,2014). Research in the field of positive psychology has increased understanding of the benefits of happiness, and how to enhance happiness.

Bao and Lyubomirsky summed up the benefits of happiness supported by experimental studies in four life domains (K. J. Bao & S. Lyubomirsky,2013). First, in social relationships, happy people tend to recall positive information about another person instead of those who feel sad (Robert,2006; Griffitt,1970). Second, in prosocial behaviour, happy people are more likely to contribute to charity (Cunningham et al.,1980). Third, in the field of creativity, happy people tend to score higher on originality and flexibility (Alice,2000). Fourth, in relation to health, a happy mood gives people a relative higher pain threshold (Andrew et al.,2001). In summary, evidence has proposed that happiness plays a large role in one's daily life.

Lyubormirsky has also confirmed how to find the key to happiness (Lyubomirsky, 2008). She explains that only 40 per cent of our happiness is within our voluntary control, 50 per cent is determined by our genes, and the other 10 per cent is related to our circumstances. Hence, opportunities are there to increase or decrease our happiness levels through our daily intentional activities. To become a happier person, we must adapt the daily actions over which we have control. To adapt our daily activities, Lyubormirsky introduced a set of 12 strategies that enhance happiness by aiming at changes in behaviour. Examples of the activities given were committing to

goals, cultivating optimism, learning to forgive, etc. These concrete strategies could be used to design for happiness.

Researchers and entrepreneurs have developed some applications based on positive psychology, from mindful meditation (Bin,2017) to reflection (Ellen,2013). However, although a great deal of scientific evidence has been collected and many applications have been proposed (Kanis,2009), methods and strategies of how designers and developers evaluate the happiness are still scarce.

The research presented in this paper is an exploration of how to evaluate the happiness from a multidimensional perspective. First, we developed a smartphone application called Collect Your Happiness (CYH). CYH can collect and store daily moments of happiness using images, videos, text, and audio. It can also give the user reminders of the collected moments to retrieve a particular positive feeling from the past and give the user small task assignments that can be completed during the day. Second, a cross-cultural measurement was conducted to evaluate the efficacy of CYH by four validated scales and PERMA model. The paper begins with a summary of the relevant background, describes the CYH approach to enhance happiness, analyzes the efficacy of this intervention using four validated scales, compares the cultural difference using Seligman's PERMA model, and discusses the design implication for happiness and research limitations.

2 Related Works

We will give a summary of interesting and proven implications based on positive psychology that is used in our application.

2.1 Happiness Interventions Mediated by Technology

Rafael Calvo and Dorian Peters categorized design practice into four classes: no

integration, preventative design, active design and dedicated design. Among them, the primary goal of the dedicated design is to support happiness. They also presented three elements of the happiness interventions mediated by technology:(1) the design for happiness can be managed pragmatically by focusing on one or more of its determinant factors (e.g., gratitude or mindfulness); (2) the design factors should draw from one or more existing theories or research evidence of happiness; (3) three design ways (preventative, active and dedicated) can be used to enhance people's happiness (R. Calvo & D. Peters,2014).

Prior research has used several methods to lead users to a state of happiness. Some of them remind people of their past experiences, such as MorningPics(Brenden,2011)and Echo (Ellen,2013), some used a technique of making the user comfortable with the execution of small daily tasks such as TinyTask (Hans,2010) and Boom Boom Cards (Boom,2008) and some encourage people to record positive things that happen in life, such as Three Good Things (Munson,2007; Seligman et al.,2005). Jeong and Breazeal developed a smartphone application that detects users' affect and provides personalized positive psychology interventions in order to enhance users' happiness (Sooyeon & Cynthia,2016). Kanis developed a mobile application called PosiPost Me to help users to create and share positive thoughts at any time and place (Kanis,2009).

In conclusion, the advantage of using technology is that it enables researchers to examine happiness in a relatively simple, inexpensive, and straightforward way (Kanis,2009). Furthermore, happiness interventions mediated by technology lower the barriers that prevent people from engaging in traditional psychotherapy (Lange et al.,2003).

However, most existing applications that enhance happiness are mainly focused

on one factor of happiness (e.g., reflection or gratitude), thus using a single exercise to improve users' happiness. On the other hand, more does not mean better. Schueller and Parks compared combinations of six types of positive-psychology exercises and found that the groups who received two or four exercises improved more happiness than those receiving the six exercises (Stephen & Acacia,2012). Therefore, their research sheds light on a specific design issue that the optimal number of exercises for one application.

2.2 Task Systems

Lyubomirsky states that the type of goal that you pursue determines whether the pursuit could make you happy (Lyubomirsky, 2008). A proper goal has the following properties: it is intrinsic, authentic, approach-oriented, harmonious, activity-based, and flexibility/appropriate. Partly with use of these properties, several tools have been designed to challenge the user with daily goals to enhance happiness (TinyTasks, Boom Boom Cards and Akoha). Tiny tasks aimed at persuading users to do new things in daily life, to change their attitude in several ways (Ruitenberg & Desmet,2012). Boom Boom Cards aimed at performing acts of kindness. Once a card is completed, the user posted the story of what happened on the website, and then passed the card on to someone else; hence Boom Boom Cards can be played in groups (Boom,2008). Akoha focused on a combination of the real and virtual world in a game in which players carried out missions that concerned acts of kindness (Akoha,2007).

In conclusion, these tools provide properly designed daily tasks to the user; the tasks are small, enjoyable, and easy to commit to. Further directions for implementing small goals in happiness strategies are given by Lyubomirsky in (Lyubomirsky, 2008), in which she states that to reach a higher-level goal, big goals have to be broken down into lower-level goals, also called sub goals. People who implement sub goals are more

likely to realize their large and abstract goals, which their higher-level goals are kept in the back of their mind. The implication of this is that the user's higher-level goal, such as increase the level of happiness, should be broken down into multiple, much simpler, sub goals given by the application.

2.3 Recording and Reflecting Systems

In addition to task systems, recording and reflecting systems are used to enhance happiness. Today, mobile life-logging tools are widely used (Twitter, Facebook, Instagram, etc.), some of them not only log your special moments, but also remind you of these moments after time has passed (MorningPics, Memoir, Timehop, and Echo). A tool called Echo was used for positive psychology research purposes by Isaacs et al.,(2013). This mobile application used a method called Technology-Mediated-Reflection (TMR) to show that happiness increased when users reflected on previously collected moments. In addition to several reminding tools, Seligman developed the "three good things" strategy, in which the user needed to write down three good things of that day and explained why these things had a positive effect on their daily life (Seligman et al.,2005; Mongrain & Anselmo,2012). Researchers reported that participants increased happiness and reduced depressive symptoms for the six months. In conclusion, there is a substantial and empirically body of research which suggests that recording happy or good things and reminiscing past happy experience can be a powerful way of improving people's happiness.

Our work is based on the above theories or evidence of positive psychology. It implemented three exercises including reminders from the past, tasks for the future and recordings of the moment, to enhance people's happiness. The aim of the research is to increase understanding of the design of technologies that support happiness. With good

use of multimedia in a mobile application, it is feasible to cover a large part of the user's daily life. A further goal of this re- search is to explore multidimensional methods to evaluate happiness because happiness in life is a multicomponent phenomenon (Desmet & Anna,2013).

3 A Design Case of Collect Your Happiness

Studies on positive psychology (Lyubomirsky,2008; Seligman et al.,2005) and positive computing (R. Calvo & D. Peters,2014), have concluded that a mobile application could be the best representation of how to enhance the happiness of a large group of users. Therefore, Collect Your Happiness (CYH) has been designed, an app that includes three major proven happiness interventions suitable for mobile app integration. Next, a comprehensive explanation of the design principles made in the app's design process is given.

3.1 Design principle

Based on three elements of the happiness interventions mediated by technology presented by Rafael Calvo and Dorian Peters, our work follows the following design principles:

(1) Focus on one or more of happiness factors: our work mainly focusses on positive emotion (record happy moments), motivation and engagement (small tasks), and reminiscence (reminders of the past moments).

(2) Draw from one or more existing theories or research evidence: our work includes reminders from the past, tasks for the future and recordings of the moment. They are sup- ported by three main theories or evidence, Isaacs's remind system (Isaacs,2013), Lyubomirsky's small tasks(Lyubomirsky,2008) and Seligman's three good things

(Seligman et al.,2005), respectively.

(3) Apply three design ways to enhance happiness: the primary goal of our work is to support happiness, so it is a dedicated design.

3.2 Pilot Study of the CYH System

Using the multi-platform development software Cordova (in HTML, CSS and JS), we first developed a beta version of CYH. Ten participants were recruited, 5 women and 5 men aged 20 to 28 (M= 24.0). They were asked to use CYH for ten days and evaluated by Subjective Happiness Scale (SHS) in pre-and post-test.

After ten days, we examined the efficacy of CYH on people's general happiness and found that SHS scores of 8 participants increased. The scores of the rest two did not change after using the CYH. In the feedback given by this two user, it can be concluded that the beta version of CYH did not persuade the user to use the app in spare moments like, for example, the Instagram or Facebook might do. A future version could make CYH more attractive is to gain gamification features. For example, after a few days, when enough moments are gathered, a proper effect will be felt. Overall, these responses suggest that people found CYH to be a great tool for their daily lives, and it could offer meaningful activities to the user. These feedbacks were considered in the design of the final version of CYH, developed for the iOS system. Furthermore, we will recruit more participants, spend more days and apply more happiness scales to evaluate the efficacy of CYH in future studies.

3.3 The Collect Your Happiness Application

After resolving the problems found in the pilot version, we worked out the final app on the iOS platform named Collect Your Happiness (CYH). CYH is a mobile application

whose main task is (1) to collect and store daily moments of happiness using multimedia images, videos, text, or audio; (2) to give the user reminders of the collected moments to retrieve a particular positive feeling from the past; and (3) to give the user small task assignments that can be completed during the day/moments.

Within the application, the user can collect daily moments of happiness (See Figure 1). To give the user as much freedom and as many options as possible, the most suitable media to collect a particular moment can be chosen (images, videos, text, and audio); the moments are then stored. The app can also send reminders to take a look at past moments every morning at 7:30 a.m. (see Figure 1), to provide an active start of the day. Reminders can also be opened by tapping on one of the clouds in the screen (see Figure 1).

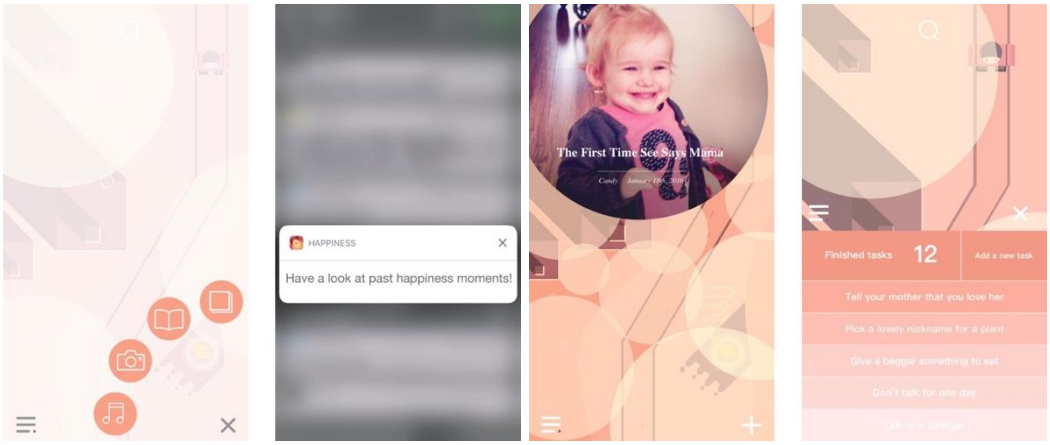

Figure 1. Interfaces of CYH: collect moments， reminder， happiness moments，tasks.

In addition to providing reminders, the app gives the user the opportunity to choose small assignments from a provided list which the users commit for that day/moment (see Figure 1). These assignments are based on an adaptation of the earlier proposed 12 strategies for the happiness of Lyubomirsky (Lyubomirsky,2005)and are enjoyable, concrete and easy to complete (see Table 1). Every assignment is a tiny execution of a happiness strategy, brought down to a very concrete and low activity

threshold. The twelve strategies of (Lyubomirsky,2008) were adapted, using the validated interventions from her experimental studies, and downscaling them to fit in people's daily lives.

CYH stores a total of 100 happiness-enhancing tasks, and the app randomly shows 10 of them daily to the user. While scrolling through the task list, the user can pick a task that best suits him or her and commits to this task during the day or moment. We have provided tasks, but the user is still free to choose a different task, as explained by Desmet, happiness- enhancing activities are meant to be personal (Desmet & Anna,2013). When the task is finished, the user can mark the task as accomplished, and of course get the opportunity to collect the task as a moment in one of the four chosen media.

Table 1. Examples of tiny tasks.

Lyubomirsky's 12	Examples of tasks in CYH
Expressing gratitude	Tell your mother that you
Cultivating optimism	Pick a lovely nickname for
Practising acts of	Give a beggar something
Avoiding social	Have a mindful mediation
Nurturing relationships	Talk to a stranger
Developing ways for	Write your bitterness
Learning to forgive	Write a friendly message
Doing more activities	Play a game for thirty
Savouring life's joys	Go to a new restaurant to
Committing to your	Plan your next journey
Practising spirituality	Read a spiritual book
Taking care of your	Go for a 2km run

4 User Study of Collect Your happiness

To measure the efficacy of the app, a user study was con- ducted. The happiness

activities of 60 participants were tracked while using CYH for four weeks. Using four happiness scales proven in positive psychology, participants' happiness levels were measured before and after usage of CYH.

4.1 Participants

Sixty-six participants were recruited via personal connections, WeChat, Facebook, and through several blogs on the Chinese web. Two participants were removed because of technical issues with phones, and four withdrew from the study. This left 30 Chinese participants: 15 women and 15 men aged 22 to 38 (M= 26.4, SD= 4.1) and 30 Dutch participants: 15 women and 15 men aged 17 to 59 (M= 33.3, SD= 13.3). Participants were separated into two nationalities because of further cross- cultural research, but for the first user study, the two groups were combined for a total of 60 participants, 30 women and 30 men, aged 17 to 59 (M= 29.6, SD= 10.0). All recruited participants had great English language ability and did not encounter any problems in the understanding of the questionnaires or application.

4.2 Procedure

Firstly, the participants were asked to complete the four questionnaires listed below to measure their happiness levels (Pre-test). Then they were given a brief introduction on CYH's functions and were asked to make frequent use of CYH for the next 28 days (four weeks). The participants were asked to use CYH several minutes per day. During these minutes, they could do some suitable tasks that were provided, collect recent positive experiences, and check out several reminders of collected moments in the past. We contacted the participants weekly by email to remind them of the program and to provide them with interesting information regarding positive psychology. After 28 days, the participants received the last email, which asked them to fill in the four

questionnaires again (Post-test), so that we could measure whether their happiness had been improved.

4.3 Data Collected

In the pre-test and post-test questionnaires, the participants were asked to complete four happiness scales:

(1) Subjective Happiness Scale (SHS): 4-item survey that assesses happiness of the self, and self-relative to others (designed by Lyubomirsky (Lyubomirsky & Lepper,1999)).

(2) Satisfaction with Life Scale (SWLS): 5-item survey that assesses overall life satisfaction (designed by Diener (Diener et al.,1985)).

(3) Psychological General Well-Being Index (PGWBI): 22-item survey that measures self-representations of affective and emotional states (designed by Dupuy (Dupuy,1984)).

(4) Mindfulness Attention Awareness Scale (MAAS): 15-item survey that measures attentiveness to what is occurring in the present (designed by Brown (Brown,2009)).

These four scales are widely used to measure happiness and demonstrate the convergent validity and test-retest reliability with a diversity of the population. In addition to the four scales in the questionnaire, the participants were questioned on their experience with the app, to provide us with helpful qualitative information for further development of CYH.

4.4 CYH improved people's happiness

We examined the efficacy of CYH on people's general happiness. Table 2 displays the mean scores before and after using CYH, which shows overall increases in happiness

after using CYH for 28 days. To test the significance of these effects, paired t-tests were conducted on the four scales respectively in pre-results and post-results. The paired t-tests outcomes show that there is a significant difference between the pre-and post-test on all the four scales. We analyzed changes and found that people's mean score of four scales including SHS (t (59) = 4.11, p <.001), SWLS (t (59) = 4.16, p <.001), PGWBI (t (59) = 3.00, p <.001), and MAAS (t (59) = 3.31, p <.001) improved after using CYH for 28 days.

5 Cross-cultural Study of CYH

5.1 Chinese and Dutch Difference in Happiness Scores

In Table 3, participants were divided into two cultural groups of the Dutch and the Chinese to measure the difference in usage of CYH. Both groups show an increase in happiness levels after using CYH for 28 days. When comparing the total pre- and post results of the Dutch and the Chinese groups, it seems that the Dutch SHS, SWLS, PGWBI and MAAS scores show a consistently higher mean on both pre- and post-test. It suggests that the Dutch happiness levels were higher than the Chinese.

Paired t-tests were conducted on the four scales in the Dutch and the Chinese, respectively. The paired t-tests outcomes show that there is a significant difference between the pre-and post-test on all the four scales for the Dutch. The mean score of four scales including SHS (t (29) = 2.33, p <.05), SWLS (t (29) = 5.03, p <.001), PGWBI (t (29) = 4.53, p <.001), and MAAS (t (29) = 2.49, p <.05) improved after using CYH for 28 days. However, the paired t-tests outcomes show that there is significant difference between the pre-and post-test on SHS (t (29) = 3.74, p <.001), SWLS (t (29) = 1.88, p <.05) and MAAS (t (29) = 2.40, p <.05) scales for the Chinese, PGWBI scale does not show significant difference.

Table 2. Mean scores before and after using CYH.

	Total group	
Scales	Pre-test	Post-test
SHS	5.11	5.38
SWLS	23.9	25.5
PGWBI	61.55	64.21
MAAS	3.65	3.94

Table 3. Mean scores before and after using CYH for both groups.

	Chinese		Dutch	
Scales	Pre-test	Post-test	Pre-test	Post-test
SHS	5.00	5.28	5.21	5.48
SWLS	22.80	24.03	25.00	26.97
PGWBI	61.10	62.69	62.00	65.73
MAAS	3.60	3.79	3.70	4.09

5.2 Cultural Happiness Difference Based on Seligman's PERMA Model

Although results show that the CYH is beneficial to both cultures, the proportion of which various elements of happiness will be larger may influence by culture. Nancy Sin and Sonja Lyubomirsky (Sin & Lyubomirsky,2009) found that positive psychology interventions have different effects on people of different cultures. For example, a person from a collectivist culture may experience more happiness when practicing prosocial and other focused activities (e.g., performing acts of kindness, having a dinner with friends or family), compared with individual-focused activities (e.g., reflecting on personal strengths). Therefore, it is interesting to study the happiness of different cultures. This research used PERMA model that was developed by Martin Seligman (Seligman,2011) to analyze the difference of happiness between the Chinese and the Dutch.

PERMA model includes 5 elements: Positive emotions, Engagement,

Relationships, Meaning, and Accomplishments. This particular model was chosen for this study because the model is very suitable for implementation in the research due to its clear categorization and scientific validation. In this analysis, all the moments collected by the participants were hand-coded by classifying each post according to its happiness element. We referred to Seligman's definitions of each domain and PERMA-Profiler and developed the coding rules. The PERMA-Profiler was a brief, validated instrument that specifically measures all five PERMA domains (Butler & Kern,2016).

The classification coding rules are as follows: (1) positive emotion: valence and arousal for positive emotion; (2) engagement: psychological interest, behavioral involvement, and concentration/focus; (3) relationships: connection with others, and giving/receiving support; (4) meaning: sense of direction, transcendence (connecting to something bigger than oneself), and sense of value/worth; (5) accomplishment: objective achievement, sense of accomplishment, and achieving personal goals.

In order to provide a further understanding of the classification method, all the categories were described and provided several examples for the researchers when coding the moments.

(1) Positive Emotions: feeling positive emotions such as joy, gratitude, serenity, interest, hope, pride, amusement, inspiration, awe, and love.

Positive emotions can be divided into two segments: (1) pleasure, which relates to satisfying bodily needs like sleep, hunger, etc., and (2) enjoyment, which comes from intellectual stimulation and creativity. Positive emotions have positive outcomes, including job success, good relationships, and better health (Lyubomirsky et al.,2005).

Example: Luka gets up this morning and comes to the balcony, and he is very happy to see that his plants had blossomed.

(2) Engagement: psychological interest, behavioural involvement, and concentration.

Achieving a state of flow with activities in which you can put all your skills to work is a very healthy state of mind. These activities could be sport, dancing, engaging in your favorite hobby, etc. Some activities can make you completely lose your sense of time (James et al.,2010).

Example: Jonathan is completely absorbed in his app's interface design. He has had great concentration and has been carefully figuring out how to design a beautiful interface.

(3) Relationships: connection with others, and giving/receiving support.

Psychological health has a very strong connection with inti- mate relationships. Nurturing relationships with strangers as well as with parents, family, friends, etc. is a great source of happiness (Taylor,2011).

Example: Tomas lives on the other side of the country for his work. Every weekend, he tries to go back home to have coffee and apple pie with his parents and goes to the local bar with his friends in the evening.

(4) Meaning: the sense of direction, transcendence.

The meaningful life involves the use strengths in the service of something bigger than oneself. Research has shown that dedicating to a religion or spiritual group can enhance someone's meaning in life (Seligman,2004).

Example: Andrew volunteers at the local youth club. He organizes club weekends, club nights, and great parties for the local youth. Every time he comes home from the club he is exhausted but feels completely meaningful. He knows that because of his offering to the community, he can contribute to the growth of many others.

(5) Accomplishments: objective achievement, sense of accomplishment, and achieving personal goals.

Having clear goals in life, small or big ones, and trying to achieve those goals, are very important to happiness. Achievement of personal goals helps enhance self-esteem, gives a strong feeling of accomplishment, and supports self-belief (Roberts et al.,2007).

Example: After a long preparation and a dozen of exams, Mike gets his driver's license that he wants for so long.

We asked the participants to share ten posts of their happiness; the first post is from the first day when participants use the CYH, and the other posts are from every two days. So, we collected 600 posts in total. For analysis, two researchers coded these posts based on the above coding rules, an agreement of 87% was achieved, and the rest of posts were coded by a third researcher in positive psychology. The results of both countries' distribution are shown in Figure 2, indicating that Chinese participants tend to collect happiness moments in Positive emotion, Relationships and Accomplishments. However, the Dutch tend to find happiness in Engagement and Meaning activities in addition to the Positive emotion and Relationships ($\chi 2$ (4) = 23.73, p <.001).

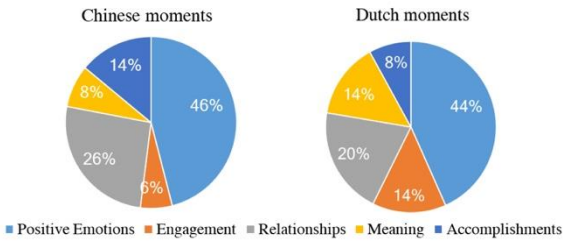

Figure 2. Cross-cultural (CN&NL) - Happiness distribution in PERMA.

When looking at the distribution of Chinese moments from CYH usage (see Figure 2 (left)), it is noticeable that the most of the moments focuses on the Positive emotions (46%), which contains moments that at least show one happy emotion like joy,

gratitude, interest, etc. The Relationships (26%) and Accomplishments (14%) take a solid second and third place. Furthermore, it can be noticed that the Meaning (8%) and Engagement (6%) are rather small and do not play a very large factor in the overall happiness distribution among Chinese participants. This could suggest that the Chinese participants seldom find their happiness in being engaged in a certain activity, and seldom find their happiness in occasions of high meaning or being part of a larger purpose in life. It can be concluded that, in general, Positive emotions and Relationships are of great importance in the Chinese participants' happy life.

Distribution of Dutch moments within the PERMA model shows a large focus on Positive emotions (44%) as well (see Figure 2 (right)), which is often expressed in enjoying certain moments, outside strolls, and sudden joyful observations. The second is Relationships (20%) which is mostly expressed in moments of birthdays, coffee breaks. Furthermore, the following parts are Meaning (14%), Engagement (14%) and Accomplishments (8%), respectively. It can be concluded that in the Dutch culture, Positive emotions and Relationships are also of great importance in their positive life.

In Figure 3, Chinese and Dutch data is set out in a radar graph to see the difference in PERMA distribution cross-culturally. Some clear conclusions can be made immediately: Positive emotions are of high importance in both cultural groups and occupy 44% (NL) and 46% (CN) respectively, with a slight difference of roughly 2%. Therefore, both groups attach importance to general positive emotions.

The second largest part for both groups is Relationships. In all the moments collected, the Chinese moments seem to contain a larger number of moments based on Relationships, the participant with a friend, family member, etc. We can connect these findings to the research done by (Nisbett,2004; Uchida & Kitayama,2009), who say that in Eastern cultures, happiness is rather experienced socially and thus in groups.

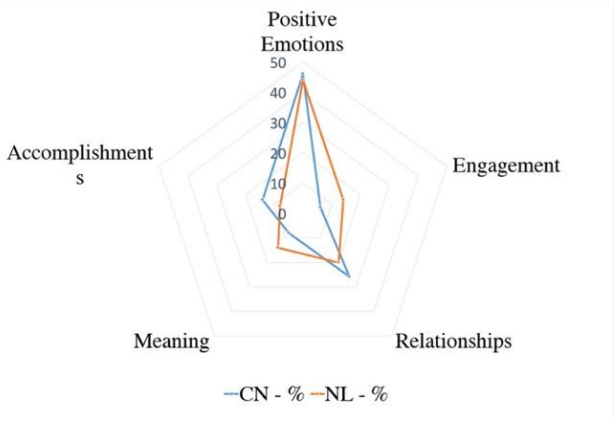

Figure 3. Radar chart of cross-cultural happiness distribution in PERMA.

Next, it can be seen that the Chinese participants show a rather higher score in Accomplishments than the Dutch participants. Chinese people find much more happiness in the accomplishment of both small and large goals.

And last, we take the Engagement (CN 6%, NL 14%) and Meaning (CN 8%, NL 14%) together for discussion. It can be concluded that Dutch participants seem to attach more value to Engagement and Meaning than Chinese participants do. According to the collected moments, Dutch happiness is based on a significant number of meaningful activities such as setting goals for certain growth, etc., and Engagement in certain daily activities done like hobbies, work, and study. A first possible reason for this phenomenon might be found in the Hofstede dimensions (Hofstede,2006) and in Nisbett's theories (Nisbett,2004) which indicate that Chinese people live in a large amount of harmony and thus seem to put less attention on how deep someone is engaged in a certain moment, but rather take it as it comes. Second, this phenomenon could be connected to the materialistic switch in Western societies described by Inglehart (2000). He describes a change in value systems in Western societies, but perhaps this shift has not been seen yet in Chinese society or has not had an impact on Chinese society yet, and therefore this lower result on Engagement and Meaning can be seen.

6 Discussion and Future Studies

We developed the CYH that combines reminders from the past, tasks for the future and recordings of the moment, to explore the theoretical and practical efficacy of happiness. Although we used four scales to evaluate the efficacy of CYH, all data were self-reported. Future assessments will benefit from combining self-reported data with objective outcomes, such as health records, or with objective methods, such as affective computing ways to evaluate the positive emotions. Furthermore, some users gave the feedback that long external questionnaire, such as PGWBI and MAAS, took quite some energy and time. Future study will use a shortened questionnaire integrated in the app, which helps give users the feedback of their happiness levels.

Results show this intervention could enhance people's happiness levels cross-culturally. However, the number of subjects, the number of countries and the testing time were not enough. It would be interesting to add more countries in the study, and more participants are needed to ensure statistical validity. Furthermore, the timeframe of conducting the research could be doubled for a more significant pre-and post-test change. Even we need to conduct the long-term investigation to explore whether the CYH could guide users to live a life with a continuous high level of happiness.

To the best of our knowledge, our study was the first to use the PERMA model for coding classification. Although we found some interesting findings between the Dutch and the Chinese through the PERMA model, a further clear classification standards and coding scheme need to be explored. Furthermore, our research focused specifically on Seligman's PERMA model, other theoretical models, such as Keyes' polythetic approach (Keyes,2002) or Huppert and So's theory (Huppert,2009) need to be tested to provide a multidimensional construct of happiness.

Regarding implication for design, the current application needs to be more

attractive to support the user in their pursuit of happiness. A sharing feature that allows users to share their happiness moments with people is being studied by us. This will not only make users willing to use the CYH but it also further helps us to explore the efficacy of social happiness.

Over the last few decades, technologies and designs not only bring functional benefits but also provide positive emotions and happiness. Our research is just a beginning to investigate the optimal ways for happiness mediated by technology. The focus of further research should address a broad approach and worldwide differences in positive psychology. Also, the smartphone is an ideal platform for conducting the Experience Sampling Method (ESM) based studies. Through smartphones, CYH can be a less time-consuming approach to collect data. CYH's data gathered in a "multimedia database of happiness" could provide happiness patterns to indicate directions for the design of happiness in the future. For instance, this database will enable a detailed exploration of the potential mental health and social benefits, such as reducing feelings of depression, increasing productivity, and awareness.

7 Conclusions

In this paper, we developed an application that provided recording positive things, reminders for the past happy moments and tasks for users to gain happiness. The CYH successfully enhance the happiness of the cross-cultural users for four weeks. We also explored the difference of happiness between the Dutch and the Chinese based on Seligman's PERMA model and established a multimedia database of happiness for future research. Despite some limitations, most users found the application helpful to improve their happiness. By directly measuring subjective and multidimensional perspectives of happiness, there is potential to more successfully promote people's

happiness. Overall, our study not only complement existing positive psychological interventions that enhance human happiness, but it also suggests novel ways of applying positive psychology principles in the future technology design.

Acknowledgments

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Thai universal design font *versus* familiar Thai text fonts: The role of distinctive letterforms and suitable inter-letter space influence in blurred words

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Abstract: To prove the performance of the first Thai universal design font (Thai UD font) on visual word recognition, the present study employed a blur simulation method and a short-exposure method for measuring the effectiveness of the Thai characters with the real words and pseudo words, compared with the Thai conventional text fonts as familiar text fonts. The results revealed that overall effectiveness on low visual acuity conditions of the Thai UD font has an advantage over the conventional text fonts. However, the findings suggest that providing sufficient inter-letter space with specific particular character pairs may enhance better visibility, especially in those letterforms which have jutted out parts (e.g., a tail, a terminal, and a loop-with-serrated-line). In other words, the characters which have a jutting part (e.g., a second-loop, a loop-with-serrated-line, and a diagonal tail) should be defined with particular sufficient inter-letter space (tracking) when they encounter with the characters which possess tight letterform or include a jutting part.

Keywords: typeface design; universal design font (UD font); legibility; visibility; pattern recognition; visual accessibility

1. Introduction

Nowadays, the growing world elderly population is a significant issue. This situation needs awareness of various aspects of the global community and in each country, mainly social and economic aspects. Organizations and institutions in each profession are trying to develop policies and practical concepts to manage this problem. Governments in each country try to promote birth rates together with providing policies for elderly care. Universities are trying to adapt to meet the needs of the aging society while social workers try to find better ways to care for the elderly to have a good quality of life. As well as in every design discipline, paying attention and having an awareness of design aids experience and well-being, for instance, in architecture, product design, and graphic design.

In positive typeface design, various fonts have been developed to address the need for increased typographic legibility and visibility. For instance, the Japanese universal design font (UD font), considered a visual acuity matter, is a common factor that affects the well-being of the elderly, visually impaired, and people with low vision. As Thailand's society matures, developing the first Thai universal design font has been initiated in order to promote the well-being of Thai people and those learning to read Thai. This initiative began with the earlier studies, which focused on improving Thai legibility and visibility, and the psychological studies on visual letter recognition, including the investigations of Punsongserm , Sunaga, and Ihara (2017a; 2017b; 2018a, and 2018b). In their studies, they applied the blur simulation method and short-exposure method for examining the performance of single Thai letterforms.

Several investigations have employed both those real words and pseudo words (also called 'non-word') in the psychological study on visual word recognition such as a

study of Dobres , Chahine, Reimer, Mehler, and Coughlin (2014) in order to measure the capability of font legibility.

Regarding pattern recognition, humans recognize a word via interpreting word shape. It may generally be a conception that in the alphabets writing system, humans recognize a word via interpreting word shape, in general reading, the skilled readers neglect to spell those familiar words and use word shape for interpretation. However, it is necessary to spell the unfamiliar words, which depends on the experience of each reader. The current study employed the use of the pseudo words in visual word recognition test so that they can reveal the intrinsic performance of the target letter which is measured together with another character.

This investigation aimed to prove the performance of the new designed Thai font that was designed based on the low visual acuity conditions and to compare with the Thai conventional text fonts. The current study employed a blur simulation method and short-exposure method for measuring the effectiveness of the Thai characters on visual word recognition and compared the findings between the two studies.

2. Test Material

2.1 Thai UD font and familiar Thai text fonts

This study employed two Thai standard text fonts to compare performance with the Thai UD font. Figure 1 exhibits the Thai alphabet of the Thai conventional text fonts (e.g., Cordia New, TH Sarabun New) along with the Thai UD font (trial version) which has distinctive letter features.

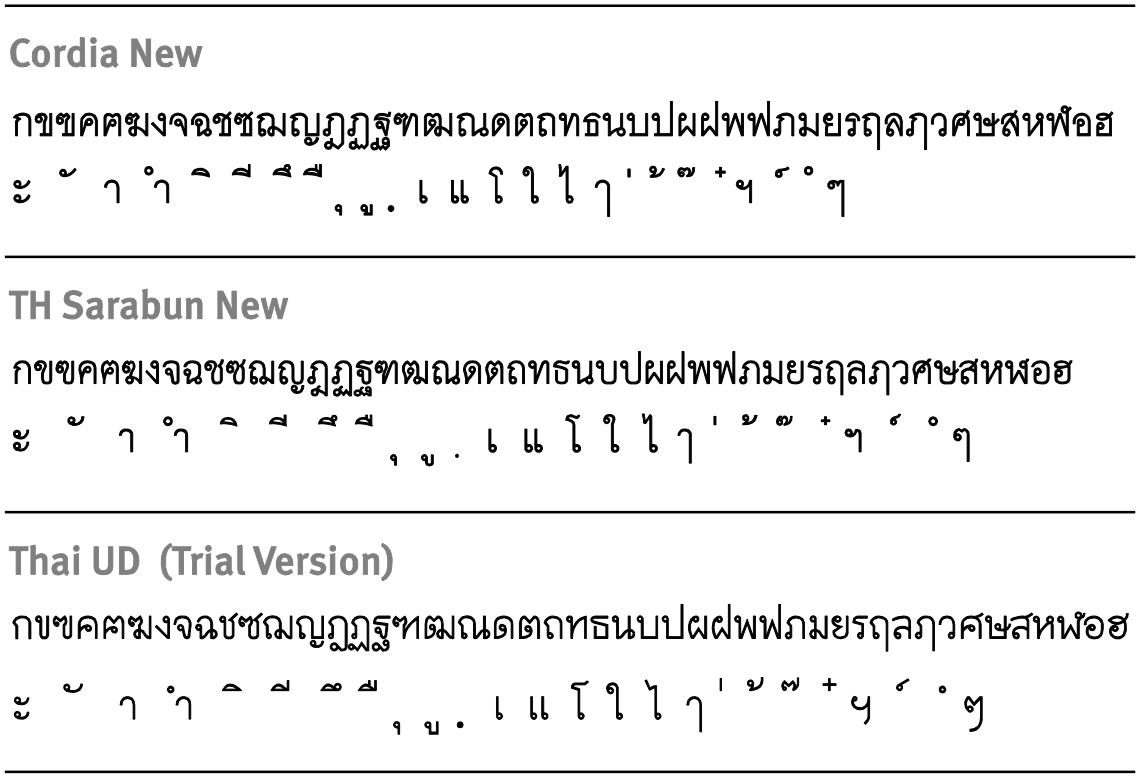


Figure 1. Alphabetical set of Cordia New, TH Saraban New, and Thai UD font

Regarding the Thai conventional text fonts, e.g., Cordia New font and TH Saraban New font, which were employed to compare performance with a Thai UD font, both Cordia New and TH Saraban New are the familiar typefaces that have been used for a long time. The root of Cordia New came from a font, e.g., Tom Light, which was designed in the late-hot metal typesetting era and used extensively in the phototypesetting era (Suveeranont, 2002; Punsongserm, 2010).

In digital typesetting era, Tom Light was converted as a digital font for both Mac OS and Windows OS. In Mac OS, the font has been called EAC Tom Light, while in Windows OS, the font was renamed as Cordia New (Cordia UPC). Cordia New and EAC Tom Light font have been included with the computers for several decades, popularly used in typing the documents.

Also, TH Saraban PSK font (original name) was one of the winning fonts from Thai font competition organized by Department of Intellectual Property (DIP) and

Software Industry Promotion Agency (SIPA) in 2007. TH Saraban PSK was declared in Thai government gazette as a font for Thai government documents, instead of Angsana New font. After that, TH Sarabun PSK font was modified and republished in 2011 under the name 'TH Sarabun New' (Suveeranont, 2017).

Regarding the structure and arrangement of the Thai UD font, the essential glyphs were digitized and generated as a font file. Figure 2, the Thai UD font (trial version) was specified boundary of the character height (fraction) as follows: upper tone mark = 0.15, upper vowel and tone mark = 0.265, consonant = 0.345, and lower vowel = 0.24, approximately.

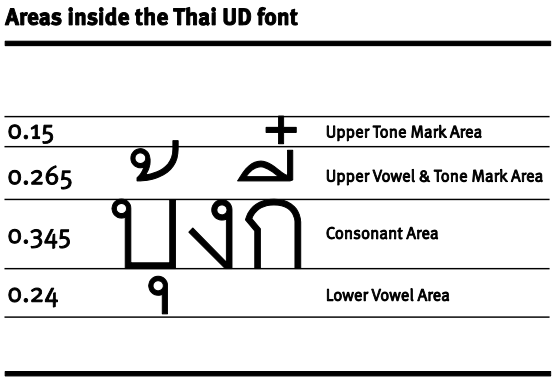


Figure 2. The specified areas inside the Thai UD font

To facilitate visibility while the Thai UD font is typed into words or sentences, arrangement of characters inside structure of the Thai UD font was arranged divergent from general Thai text font which has been prescribed followed the formula of National Electronics and Computer Technology Center (NECTEC), Thailand (Committee of Thai Font Standardization, 2001). Figure 3 illustrates the arrangement of the characters in the Thai UD font (upper part), compared with a general Thai text font (lower part). Remark that arrangement of the characters in the general Thai text font (e.g., the upper tone mark, upper-vowel-and-tone-mark, and lower vowel) align with the backlines of each consonant, while in the Thai UD font avoid the alignment and intent to breaking

rules of Gestalt (law of closure) with indenting slight forward for the upper characters and the lower characters. As an assumption, this arrangement may encourage superior visibility in a situation of low visual acuity with the encompassing characters; see a comparison in blur simulation between the words which were with the Thai UD font and a general Thai text font (TH Saraban New), Figure 3.

However, in the case of some upper vowels and tone marks such as Maitaikhu ็/, Mai Tho ้/, Mai Tri ๊/, and Mai Chattawa ๋/, were aligned with the backlines of each consonant. Moreover, the characters Mai-Hanakat ั/ (upper vowel) and Thanthakhat ์/ (sign) were not aligned with the backlines of each consonant. They were positioned for indenting slightly backwards, jut out the axis of the backlines of the consonants (see Figure 3).

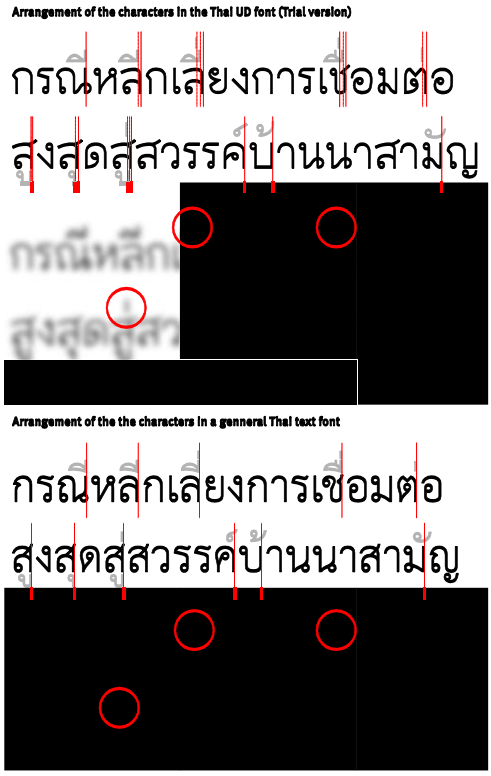


Figure 3. A comparison between the arrangement of the characters in the Thai UD font and a general Thai text font

2.2 The characters for testing

The current study examined the effectiveness of the thirty-one characters which are the frequently misrecognized letters (Punsongserm, Sunaga, & Ihara, 2017), except the four characters (Kho Khon) /ค/, (Kho Khuat) /ฃ/, Maiyamok /ๆ/, and Paiyannoi /ฯ/. The characters (Kho Khon) /ค/, (Kho Khuat) /ฃ/ was not tested due to there are no real words which these characters were prescribed as Thai words, while the characters Maiyamok /ๆ/, and Paiyannoi /ฯ/ are a repetition mark and a sign which are commonly used at the end of the word. Hence, the four characters did not appear in the present study as the main characters which were tested in real words. Table 1 shows the target characters (31 characters) along with their common confused pairs.

2.3 The Words for Testing

In this study, the selected characters were measured for their performance on visual words recognition throughout the real words and pseudo words under eight conditions which provided difference encompassing for the target characters.

The present study employed the Thai words from the Thai dictionaries and the common Thai words which are used generally among Thai (see Appendix). The main letters in the real words were substituted by those confused pair letters (which have noted in Table 1) as the pseudo words (see Appendix). Figure 4 illustrates an example of the words focus on the letter To Tao /ต/ which was composed to the real words and the pseudo words with the eight conditions. The green letters are the real letters, while the red letters are the confused pair letters of the real letters, as well as the black letters are the vowels and tone marks.

Table 1. The selected characters with their common confused pairs

Characters	Confused Pairs			
01 To Tao /ต/	ต	ค	ด	
02 Tho Thung /ถ/	ก	ฉ		
03 Cho Chan /จ/	ข	ล	ฉ	
04 Cho Ching /ฉ/	ฮ	น		
05 Do Chada /ฎ/	ฎ	ฦ	ฤ	
06 To Patak /ฏ/	ฎ			
07 Tho Thong /ธ/	ช	ฮ	ข	
08 Ro Rua /ร/	ช	ข		
09 So Sala /ศ/	ส	ค		
10 So Sua /ส/	ศ	ฮ		
11 O Ang /อ/	ฮ	ล		
12 Ho Nokhuk /ฮ/	ส	อ	ธ	
13 Kho Khai /ข/	ช	ฃ		
14 Cho Chang /ช/	ซ	ข		
15 So So /ซ/	ช	ข	ฃ	
16 Tho Thahan /ท/	ห	ฑ		
17 Tho Nangmontho /ฑ/	ท	ห		
18 No Nu /น/	ม	ผ	บ	
19 Mo Ma /ม/	บ	ฆ	ย	น
20 Bo Baimai /บ/	ย	ข	ม	น
21 Yo Yak /ย/	ม	บ	น	ข
22 Pho Phung /ผ/	พ	ย	ม	น
23 Lo Chula /ฬ/	พ	ห	ฟ	

Characters	Confused Pairs				
24 Sara Ai Maimalai /ไ/	ใ	โ			
25 Sara O /โ/	ใ	ไ			
26 Sara Ae /แ/	น	ฉ			
27 Sara Ii /◌ี/	◌ั	◌ิ	◌ิ	◌ี	◌ี
28 Sara Ue /◌ึ/	◌ิ	◌ั	◌ี	◌ิ	◌ิ
29 Sara Uee /◌ื/	◌ิ	◌ิ	◌ั	◌ี	◌ิ
30 Mai Han-akat /◌ั/	◌้	◌็	◌ิ		
31 Mai Tho /◌้/	◌้	◌็	◌ิ		

3. Methods

3.1 Experiment 1: Blur Simulation Test

3.1.1 Character Height

In order to maintain consistency of equivalent character size, this experiment applied the method of stipulating character height (Legge & Bigelow, 2011) (i.e., x-height) in this study. The Bo Baimai heights of the selected characters were 4 mm (11 pixels in the display we used). The point size at 4 mm of Bo Baimai heights of each font was 28.35 points (Cordia New), 28.9 points (TH Sarabun New), and 34.1 points (Thai UD). Thus,

the conversion to visual angle (in degrees) from the physical print size was 0.572 °of 4 mm, at a viewing distance of 40 cm. The stimulus characters were presented in black on a white background.

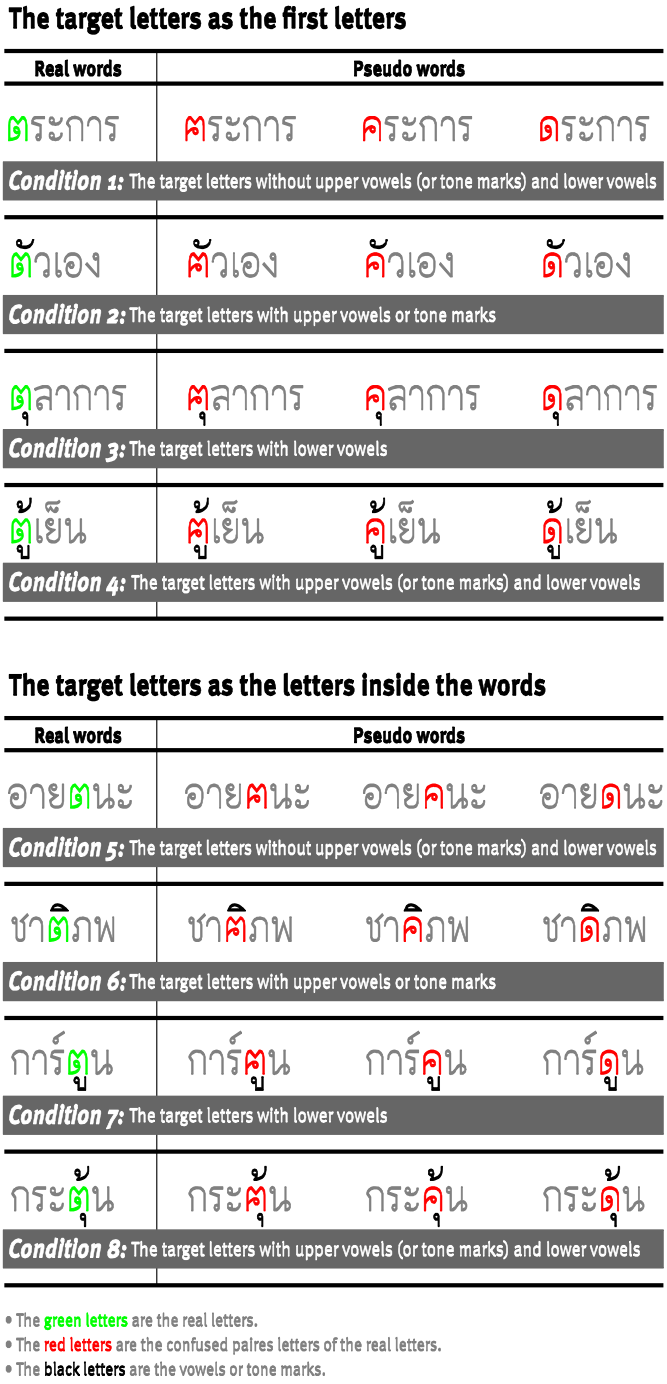


Figure 4. An example of real words and the pseudo words with eight conditions of encompassing, letters To Tao /ต/

3.1.2 Participants

A sample of 15 native Thai volunteers, including 3 males and 12 females aged between 20 and 29 years old (average: 21.1 years), participated in this experiment. All participants had normal or corrected-to-normal visual acuity.

3.1.3 Apparatus

The Thai words as stimuli were displayed on BenQ BL2711U 27 inch UHD Monitor with identical resolution (3840 px × 2160 px) and refresh rate (30 Hz), and a luminous intensity of 258 cd/m2. This experimentation was conducted in a dark box (W100 × L150 × H200 cm). An adjusted-to-vertical monitor with a chinrest was placed on a desk. The distance between the vertical monitor and the chinrest was approximately 40 cm. Observers viewed the screen with their binocular vision while their head maintained against a chin-and-forehead rest. They responded each perceived word via a Thai keyboard with backlighted characters (Marvo KM400).

A blurred glass in size 280mm x 356mm was employed to simulate the condition of low visual acuity as if those spatial filters were applied by Legge, et al. (1985), Nakano et al. (2010), and Arai et al. (2010), and Punsongserm et al. (2018a). The blurred glass was placed approximately 5 cm from the front of the monitor.

3.1.4 Procedure

First of all, when a participant pressed the space key, a stimulus character with a set of force choices was presented on the screen in a randomized order. Second, the participant perceived and identified the stimulus character, one by one. Participants could choose a choice by pressing the arrow keys on the Thai keyboard, the perceived character, and then pressing enter key for confirmation (see Figure 5). In this experiment, the 792 Thai words, including 213 real words and 579 pseudo words, which

composed by the three fonts (Thai UD font and Thai conventional text fonts) and giving a total of 2,376 stimulus words. The words were randomized and presented individually with three repetitions, giving a total of 7,128 trials.

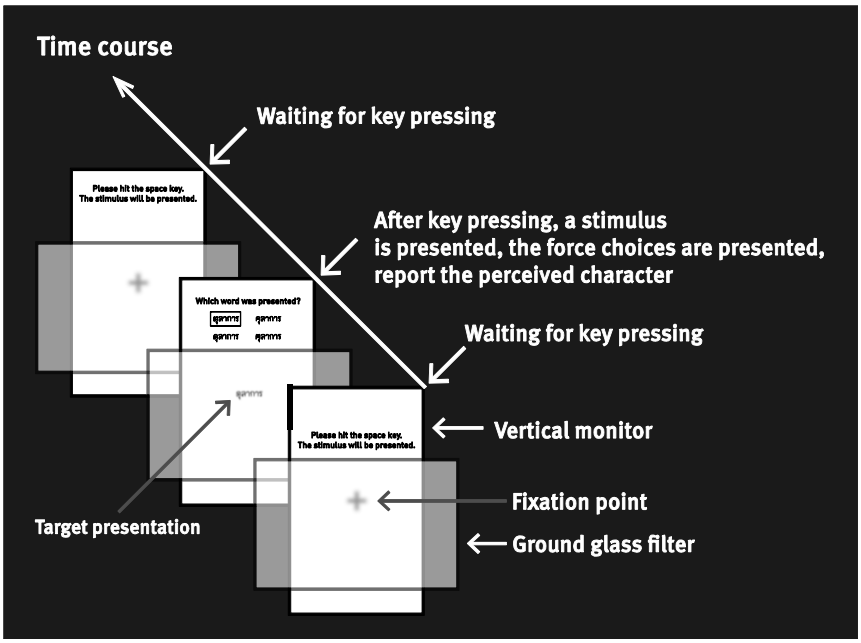


Figure 5. Sequence of events in the blur simulation experiment

3.2 Experiment 2: Short-Exposure Tests

3.2.1 Participants

A sample of 15 native Thai volunteers, including 4 males and 11 females aged between 20 and 23 years old (average: 21 years), participated in this experiment. All participants had normal or corrected-to-normal visual acuity.

3.2.2 Apparatus and Stimulus

This experiment used the same equipment applied in experiment 1. All of the same stimuli of experiment 1 were also applied in this experiment. They had the same property of character height. The stimulus characters were presented at a distance of 20 mm from the fixation point in a direction randomly chosen from 2 directions; top and

bottom of fixation point (see Figure 6, right). The retinal eccentricity of the stimulus presentation was 2.86°, corresponding to the middle parafoveal area (Rayner, et al., 2016; Schotter, Angele, & Rayner, 2012; Punsongserm et al., 2018b).

3.2.3 Procedure

To measure the performance effects of the words in parafoveal vision, this experiment employed the short-exposure method with two different durations (200-ms and 300-ms conditions) to examine the selected words. This method enabled us to acquire parallel data in the series, which can be advantageous compared with obtaining only a single data set. The experiment was divided into two tasks: the short-exposure test with presentations of 200 ms, and the short-exposure test with presentations of 300 ms. The 792 words of each font were randomized and presented individually with three repetitions, giving a total of 2,376 stimulus words, (7,128 stimulus words with the three font). Each word appeared briefly for either 200 ms or 300 ms. The short-exposure condition with 200 ms presentation included 7,128 stimulus characters, and the 300 ms condition included 7,128 stimulus characters, giving a total of 14,256 trials.

Each participant sat on a comfortable chair, and maintained fixation on a vertical screen with binocular vision, while their head was positioned on chin and forehead rests. When participants pressed the space key, a stimulus character was presented for a short duration (200 or 300 ms) at one of 2 positions upper and lower the fixation point, selected randomly. A mask then appeared for 400 ms in order to eliminate afterimage. Participants could choose a choice by selecting via the arrow keys on the Thai keyboard, the perceived character, and then pressing the enter key for confirmation (see Figure 6, left).

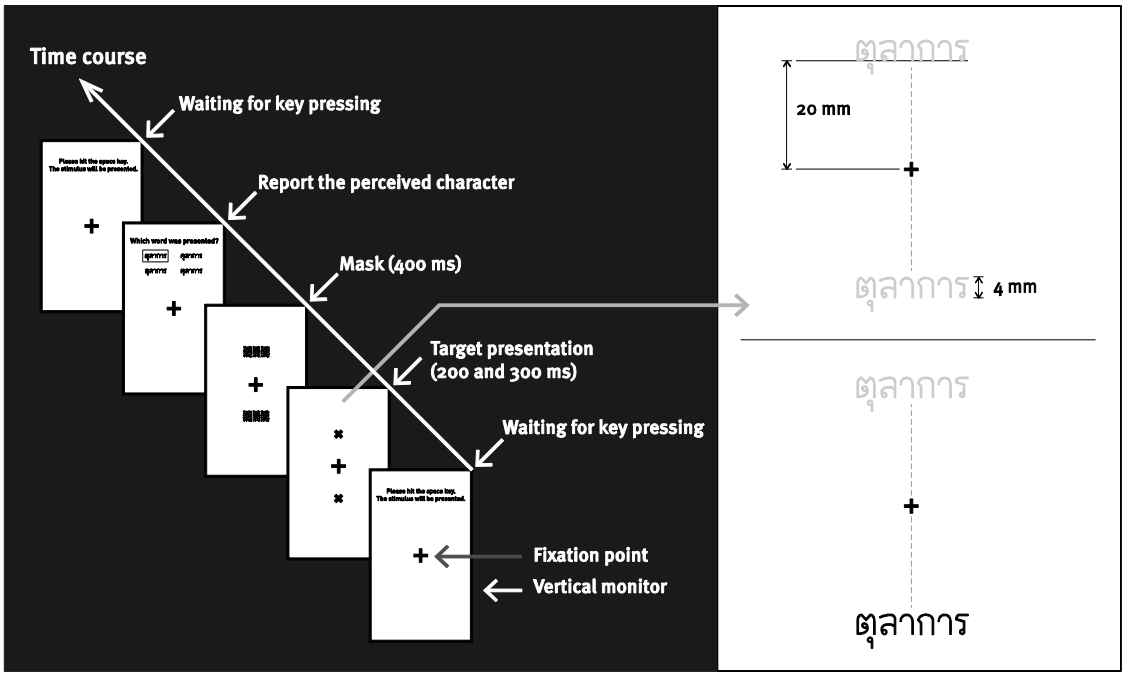


Figure 6. Left: Sequence of events in the short-exposure experiments. Right: Character height consorts Bo Baimai height, distance from fixation (on fovea, plus symbol) to stimulus character (on parafovea).

4. Results and Discussion

The current study used inferential statistics with the chi-square test to analyze the rates of correct and incorrect answers that were collected with each stimulus character test. The results of the blur simulation test for each character set were also compared with the results of the short-exposure tests.

The present study tested the thirty-one characters as real words along with the eighty-six characters as the substitute characters which were examined as pseudo words context, as shown in Table 2 and Table 3. Thus, the results have produced 117 sets of the findings.

Table 2. List of the characters tested in the real words along with the substitute characters which were examined as pseudo words context

No.	The characters were ested in the real words	The substitute characters were tested in the pseudo words context
	Consonants	
1	ฅ	*No Character*
2	ฆ	*No Character*
3	จ	*No Character*
4	ฉ	/ฉ ⟶ ถ/, /ฉ ⟶ จ/, /ฉ ⟶ แ/
5	ฌ	/ฌ ⟶ ฏ/
6	ฏ	/ฏ ⟶ ฌ/
7	ธ	/ธ ⟶ ฮ/
8	ร	*No Character*
9	ศ	/ศ ⟶ ส/
10	ส	/ส ⟶ ฮ/, /ส ⟶ ศ/
11	อ	/อ ⟶ ฮ/
12	ฮ	/ฮ ⟶ ฉ/, /ฮ ⟶ ธ/, /ฮ ⟶ ส/, /ฮ ⟶ อ/
13	ข	/ข ⟶ จ/, /ข ⟶ ธ/, /ข ⟶ ร/, /ข ⟶ ช/, /ข ⟶ ซ/, /ข ⟶ บ/, /ข ⟶ ย/
14	ช	/ช ⟶ ธ/, /ช ⟶ ร/, /ช ⟶ ข/, /ช ⟶ ซ/
15	ซ	/ซ ⟶ ช/
16	ท	/ท ⟶ ฑ/
17	ฑ	/ฑ ⟶ ท/
18	น	/น ⟶ ฉ/, /น ⟶ ม/, /น ⟶ บ/, /น ⟶ ย/, /น ⟶ ผ/, /น ⟶ แ/
19	ม	/ม ⟶ น/, /ม ⟶ บ/, /ม ⟶ ย/, /ม ⟶ ผ/
20	บ	/บ ⟶ น/, /บ ⟶ ม/, /บ ⟶ ย/
21	ย	/ย ⟶ ม/, /ย ⟶ บ/, /ย ⟶ ผ/
22	ผ	/ผ ⟶ น/
23	ฟ	*No Character*

Table 3. List of the characters tested in the real words along with the substitute characters which were examined as pseudo words context (continue)

No.	The characters were ested in the real words	The substitute characters were tested in the pseudo words context
	Consonants	
24	*No Character*	/ฅ ⟶ ต/
25	*No Character*	/ค ⟶ ต/, /ค ⟶ ศ/
26	*No Character*	/ด ⟶ ต/
27	*No Character*	/ก ⟶ ถ/
28	*No Character*	/ล ⟶ จ/, /ล ⟶ อ/
29	*No Character*	/ข ⟶ ข/, /ข ⟶ ช/
30	*No Character*	/ห ⟶ ท/, /ห ⟶ ฑ/, /ห ⟶ ฬ/
31	*No Character*	/ฆ ⟶ ม/
32	*No Character*	/พ ⟶ ผ/, /พ ⟶ ฟ/
33	*No Character*	/ฟ ⟶ ฟ/
	Vowels and Tone Marks	
34	ไ	/ไ ⟶ โ/
35	โ	/โ ⟶ ไ/
36	แ	*No Character*
37	อี	/◌ี ⟶ ◌ี/, /◌ี ⟶ ◌ี/
38	อื	/◌ื ⟶ ◌ื/, /◌ื ⟶ ◌ื/
39	อื	/◌ื ⟶ ◌ื/, /◌ื ⟶ ◌ื/
40	อั	/◌ั ⟶ ◌ั/
41	อั้	/◌ั ⟶ ◌ั/
42	*No Character*	/ใ ⟶ ไ/, /ใ ⟶ โ/
43	*No Character*	/◌ั ⟶ ◌ี/, /◌ั ⟶ ◌ื/, /◌ั ⟶ ◌ื/, /◌ั ⟶ ◌ั/, /◌ั ⟶ ◌ั/
44	*No Character*	/◌ิ ⟶ ◌ี/, /◌ิ ⟶ ◌ื/, /◌ิ ⟶ ◌ื/
45	*No Character*	/◌ี ⟶ ◌ี/, /◌ี ⟶ ◌ื/, /◌ี ⟶ ◌ื/, /◌ี ⟶ ◌ั/, /◌ี ⟶ ◌ั/

Due to the current study produced inordinate results, we cannot present all of the findings. Hence, we then selected only the noticeable results which can provide inclusively explain to the role of distinctive letterforms and suitable inter-letter space influence in blurred words. The selected results include the findings of the eleven characters, e.g., the characters /ฎ/ (Do Chada), /ฏ/ (To Patak), /ช/ (Cho Chang), /ซ/ (So So), /ไ/ (Sara Ai Maimalai), /โ/ (Sara O),◌ี/ (Sara Ii),◌ื/ (Sara Ue),◌ื/ (Sara Uee),◌ั/ (Mai Han-akat), and◌ั้/ (Mai Tho).

(1) The Characters /ฎ/ (Do Chada)

Real words: In the blur simulation test, most findings of Thai UD font words had a higher misidentification rate than the conventional text fonts. However, in short-exposure tests, the rate of error in each font was equal, sometimes Thai UD font obtained an incorrect response rate less than the other fonts (see Figure 8). Regarding the findings of the word ‘กุฎาคาร’ in condition 5B suggests that should adjust a position of the character Sara U /ุ/ away from a loop-with-coiled-tail of the character Do Chada /ฎ/. Also, providing more front-space for the character Do Chada /ฎ/ could support visibility (see Figure 7). This solution may include adding back-space for the character So Rusi /ษ/.

Pseudo words: In the condition 2 with the character Do Chada /ฎ/ substituted To Patak /ฏ/, the findings of a word ‘ฎังการ’ exhibited a lower misreading rate in the blur simulation test and the short-exposure tests, whereas in condition 5A, 5B, and 6 (e.g., the words ‘นาฎศิลป์’, ‘ปรากฎ’, and ‘ปฏิบัติ’), the incorrect response rate was increased (see Figure 9). The findings suggest adding front space in character Do Chada /ฎ/ may contribute to visibility.

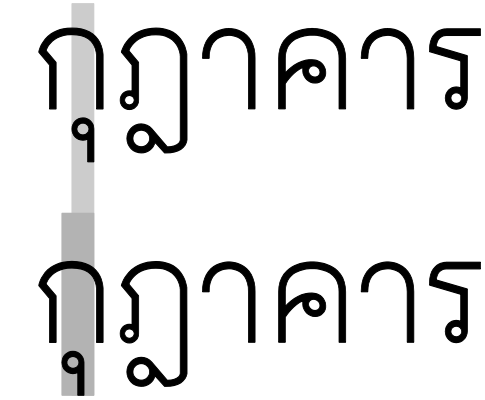
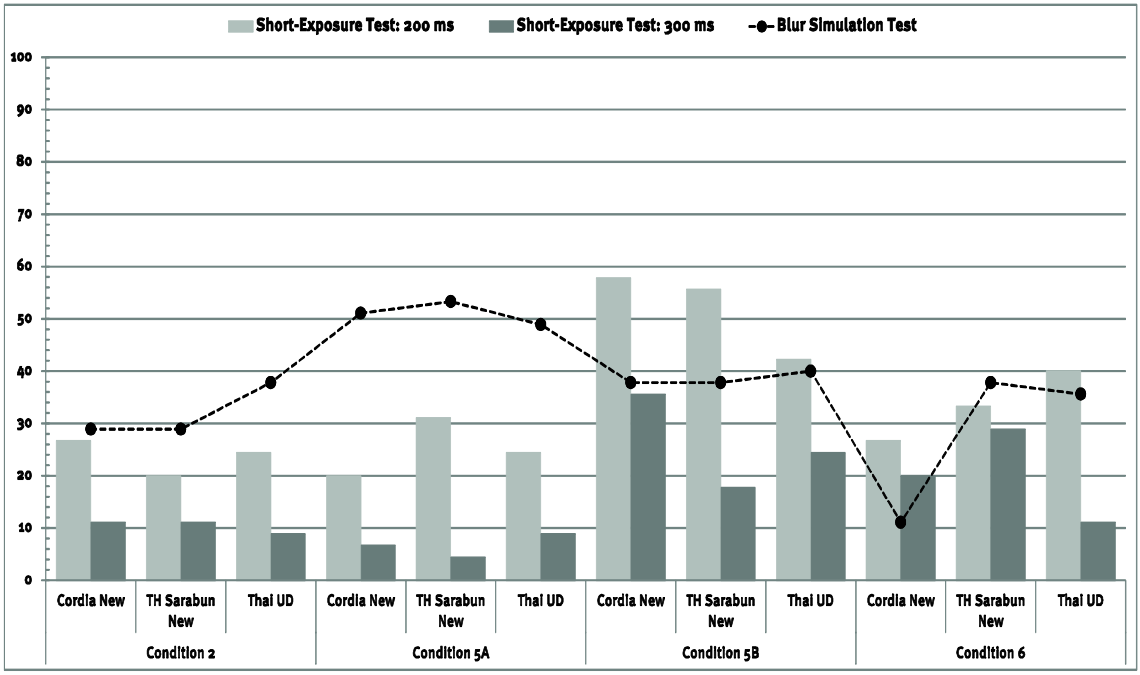


Figure 7. Approach to adjusting a position of the character Sara U /ุ/

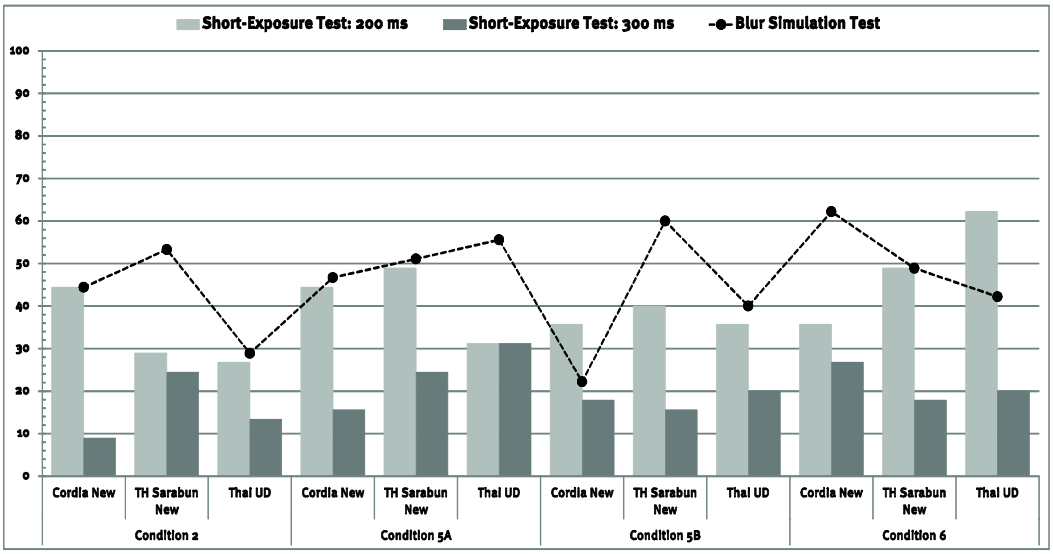


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 2	Cordia New	28.9 ns	26.7 ns	11.1 ns
	TH Sarabun New	28.9 ns	20 ▽*	11.1 ns
	Thai UD	37.8 ns	24.4 ns	8.9 ns
Condition 5A	Cordia New	51.1▲*	20 ▽*	6.7 ▽+
	TH Sarabun New	53.3 ▲*	31.1 ns	4.4 ▽*
	Thai UD	48.9 ▲+	24.4 ns	8.9 ns
Condition 5B	Cordia New	37.8 ns	57.8 ▲**	35.6 ▲**
	TH Sarabun New	37.8 ns	55.6 ▲**	17.8 ns
	Thai UD	40 ns	42.2 ns	24.4 ▲+
Condition 6	Cordia New	11.1 ▽**	26.7 ns	20 ns
	TH Sarabun New	37.8 ns	33.3 ns	28.9 ▲*
	Thai UD	35.6 ns	40 ns	11.1 ns

Chi-square	$\chi^2(11) = 27.302$	$\chi^2(11) = 36.790$	$\chi^2(11) = 35.004$
	P-value = .002	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 8. The characters /ฎ/ (Do Chada) (Real words)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 2	Cordia New	44.4 ns	44.4 ns	8.9
	TH Sarabun New	53.3 ns	28.9 ns	24.4
	Thai UD	28.9 ▽*	26.7 ▽+	13.3
Condition 5A	Cordia New	46.7 ns	44.4 ns	15.6
	TH Sarabun New	51.1 ns	48.9 ns	24.4
	Thai UD	55.6 ns	31.1 ns	31.1
Condition 5B	Cordia New	22.2 ▽**	35.6 ns	17.8
	TH Sarabun New	60 ▽+	40 ns	15.6
	Thai UD	40 ns	35.6 ns	20
Condition 6	Cordia New	62.2 ▲*	35.6 ns	26.7
	TH Sarabun New	48.9 ns	48.9 ns	17.8
	Thai UD	42.2 ns	62.2 ▲**	20

Chi-square	$\chi^2(11) = 28.035$	$\chi^2(11) = 21.164$	$\chi^2(11) = 12.067$
	P-value = .002	P-value = .031	P-value = .342
Significant Difference	Yes	Yes	No

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 9. The characters /ฎ/ (Do Chada) substituted the characters /ฏ/ (To Patak)

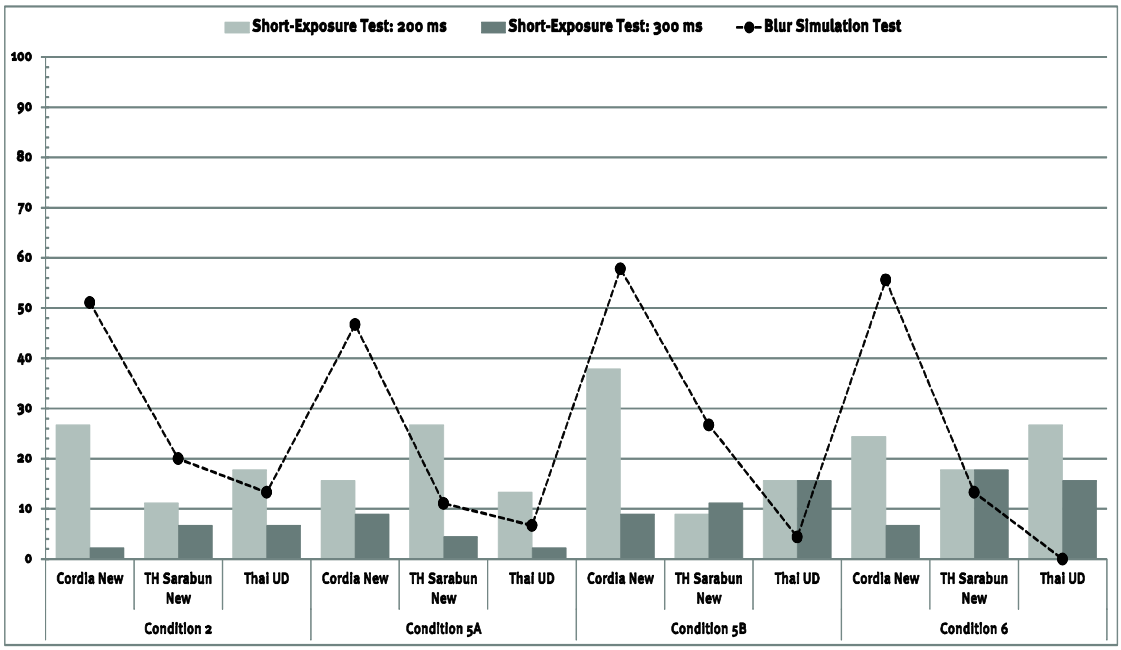
(2) The Characters /ฏ/ (To Patak)

Real words: The findings of the Thai UD font words had the lowest misreading rate in the blur simulation test and obtained a lower incorrect response rate in the short-exposure tests (see Figure 11). Same as a suggestion in the result of the character Do Chada /ฎ/, providing more front space, particularly in the case that To Patak /ฏ/ is

placed behind a character which has a back solid vertical line such as the character Po Pla /ป/ (e.g., a word ‘ปฏิบัติ’ in condition 6). This way could reduce confusion caused low visibility (see Figure 10).

Pseudo words: In the conditions 2 and 5, the words of the Thai UD font revealed a lower misidentification rate than the results in the conventional text fonts. However, in the condition 6 with a word ‘ดุษฎี’ the three fonts had a higher incorrect response rate (see Figure 12). This finding reflects the essential need of providing more front-space for the character To Patak /ฏ/, including extending back-space in character So Rusi /ษ/ will reinforce better visibility.

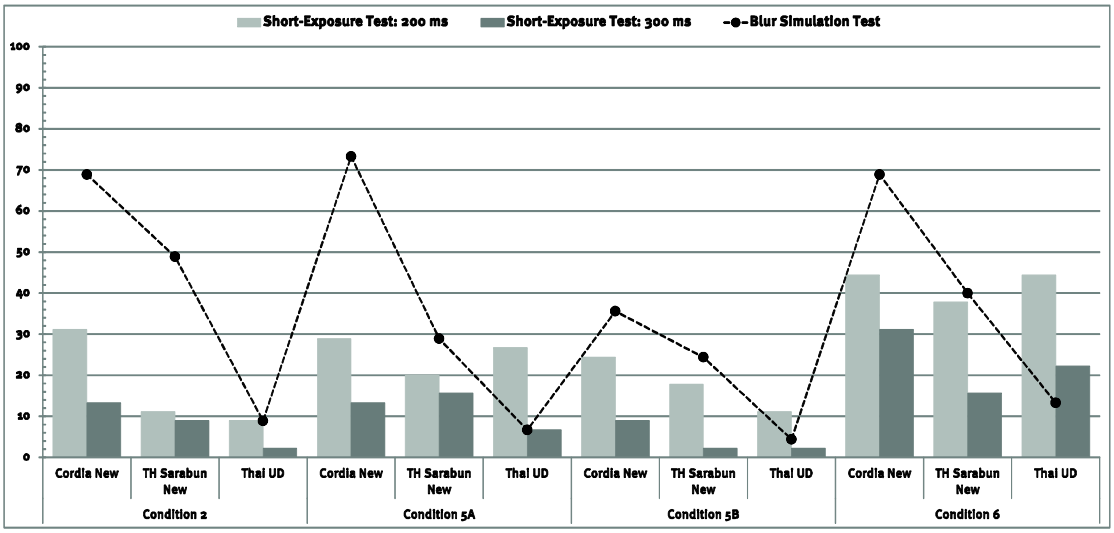
Figure 10. An example of improving inter-letter space of the character pairs Po Pla /ป/ - To Patak /ฏ/ and So Rusi /ษ/ - To Patak /ฏ/



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 2	Cordia New	51.1▲**	26.7 ns	2.2
	TH Sarabun New	20 ns	11.1 ns	6.7
	Thai UD	13.3 ▽*	17.8 ns	6.7
Condition 5A	Cordia New	46.7▲**	15.6 ns	8.9
	TH Sarabun New	11.1 ▽*	26.7 ns	4.4
	Thai UD	6.7 ▽**	13.3 ns	2.2
Condition 5B	Cordia New	57.8 ▲**	37.8 ▲**	8.9
	TH Sarabun New	26.7 ns	8.9 ▽*	11.1
	Thai UD	4.4 ▽**	15.6 ns	15.6
Condition 6	Cordia New	55.6 ▲**	24.4 ns	6.7
	TH Sarabun New	13.3 ▽*	17.8 ns	17.8
	Thai UD	0 ▽**	26.7 ns	15.6
Chi-square		$\chi^2(11) = 119.027$	$\chi^2(11) = 21.368$	$\chi^2(11) = 16.463$
		P-value = .000	P-value = .032	P-value = .109
Significant Difference		Yes	Yes	No

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
ns = not significant at p>0.1

Figure 11. The errors in the characters /ฏ/ (To Patak) (Real words)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 2	Cordia New	68.9 ▲**	31.1 ns	13.3 ns
	TH Sarabun New	48.9 ▲*	11.1 ▽*	8.9 ns
	Thai UD	8.9 ▽**	8.9 ▽**	2.2 ▽*
Condition 5A	Cordia New	73.3 ▲**	28.9 ns	13.3 ns
	TH Sarabun New	28.9 ns	20 ns	15.6 ns
	Thai UD	6.7 ▽**	26.7 ns	6.7 ns
Condition 5B	Cordia New	35.6 ns	24.4 ns	8.9 ns
	TH Sarabun New	24.4 ns	17.8 ns	2.2 ▽*
	Thai UD	4.4 ▽**	11.1 ▽*	2.2 ▽*
Condition 6	Cordia New	68.9 ▲**	44.4 ▲**	31.1 ▲**
	TH Sarabun New	40 ns	37.8 ▲*	15.6 ns
	Thai UD	13.3 ▽**	44.4 ▲**	22.2 ▲*
Chi-square		$\chi^2(11) = 138.532$	$\chi^2(11) = 40.065$	$\chi^2(11) = 35.877$
		P-value = .000	P-value = .000	P-value = .000
Significant Difference		Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
ns = not significant at p>0.1

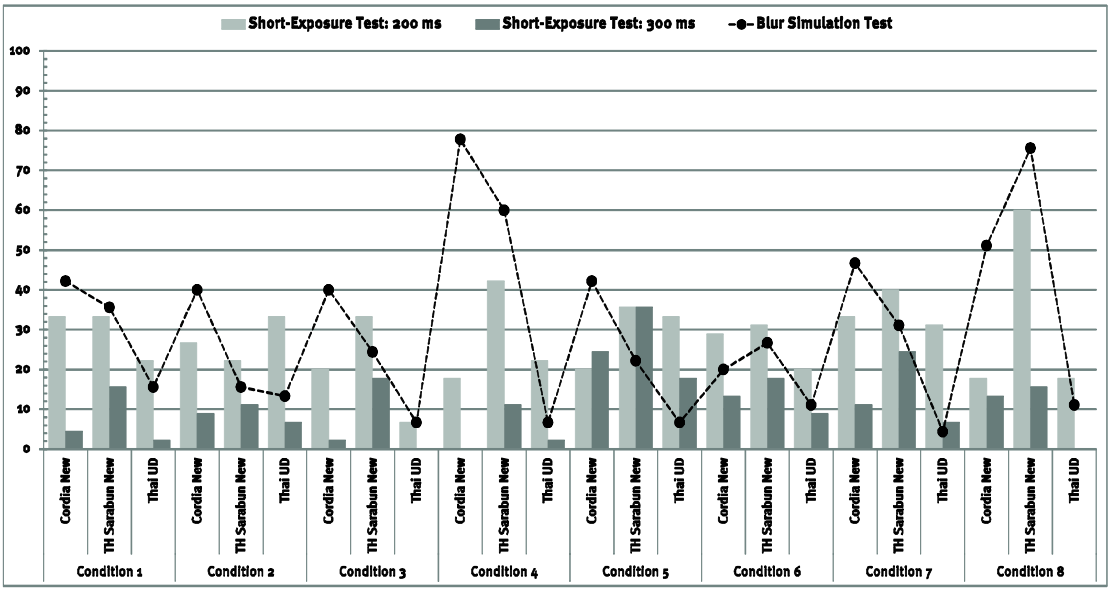
Figure 12. The errors in the characters /ฏ/ (To Patak) substituted the characters /ฎ/ (Do Chada)

(3) The Characters /ช/ (Cho Chang)

Real words: In the blur simulation test, the Thai UD font acquired the lowest incorrect response rate, superior to the conventional text fonts. There was no more than 10% and sometimes no error rate in 300-ms short-exposure test for the Thai UD font, while in 200 ms test most results had a lower misidentification rate than the other fonts,

except in the condition 2 (a word ‘ชัยนาท’) which revealed the highest error rate (see Figure 13).

Pseudo words: The most findings of the UD font had a lower incorrect response rate than the conventional text fonts in the blur simulation test, unless in some conditions which the character Cho Chang /ช/ is close to the upper vowels Sara I ิ/, Sara Ii ี/, Mai Han-Akat ั/, and Mai tho ้/ (in the words ‘สนชิสัญญา’, ‘ตชีคูณ’, ‘ชัญญาหาร’, and ‘กินช้าว’, respectively) (see Figure 14 – 17). However, in the short-exposure tests, the findings indicated that it had a very high error for the tested fonts, particularly in the characters Cho Chang /ช/ which substituted in So So /ซ/, evident in the 200-ms short-exposure tests (see Figure 14).

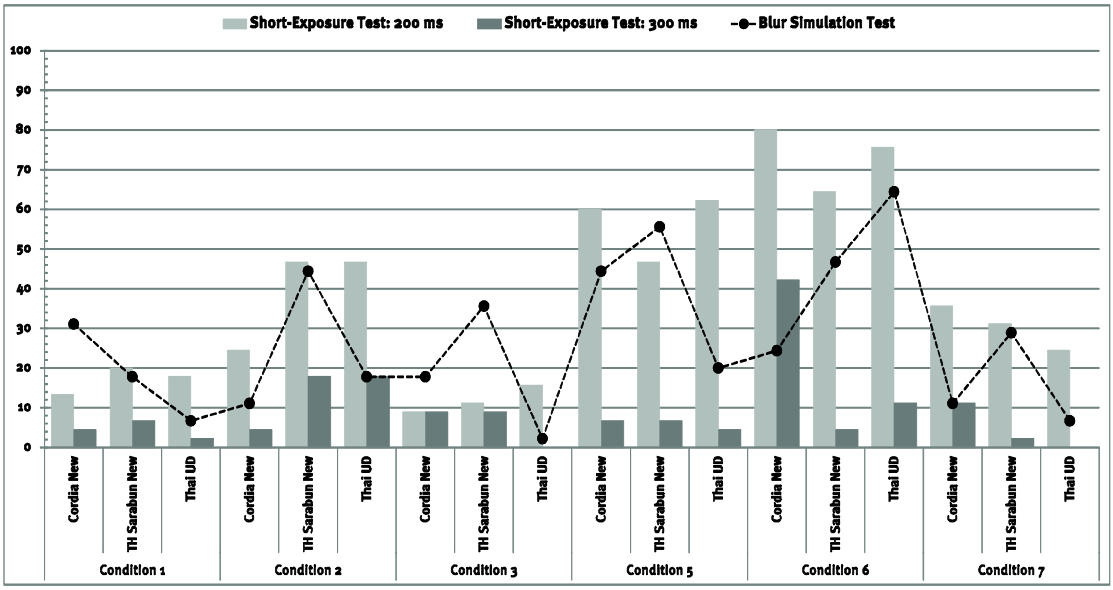


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 1	Cordia New	42.2 ▲+	33.3 ns	4.4 ns
	TH Sarabun New	35.6 ns	33.3 ns	15.6 ns
	Thai UD	15.6 ▽*	22.2 ns	2.2 ▽*
Condition 2	Cordia New	40 ns	26.7 ns	8.9 ns
	TH Sarabun New	15.6 ▽*	22.2 ns	11.1 ns
	Thai UD	13.3 ▽*	33.3 ns	6.7 ns
Condition 3	Cordia New	40 ns	20 ns	2.2 ▽*
	TH Sarabun New	24.4 ns	33.3 ns	17.8 ns
	Thai UD	6.7 ▽**	6.7 ▽**	0 ▽*
Condition 4	Cordia New	77.8 ▲**	17.8 ns	0 ▽*
	TH Sarabun New	60 ▲**	42.2 ▲*	11.1 ns
	Thai UD	6.7 ▽**	22.2 ns	2.2 ▽*
Condition 5	Cordia New	42.2 ▲+	20 ns	24.4 ▲**
	TH Sarabun New	22.2 ns	35.6 ns	35.6 ▲**
	Thai UD	6.7 ▽**	33.3 ns	17.8 ns
Condition 6	Cordia New	20 ns	28.9 ns	13.3 ns
	TH Sarabun New	26.7 ns	31.1 ns	17.8 ns
	Thai UD	11.1 ▽**	20 ns	8.9 ns
Condition 7	Cordia New	46.7 ▲*	33.3 ns	11.1 ns
	TH Sarabun New	31.1 ns	40 ▲+	24.4 ▲**
	Thai UD	4.4 ▽**	31.1 ns	6.7 ns
Condition 8	Cordia New	51.1 ▲**	17.8 ns	13.3 ns
	TH Sarabun New	75.6 ▲**	60 ▲**	15.6 ns
	Thai UD	11.1 ▽**	17.8 ns	0 ▽*

Chi-square	$x^2(23) = 221.863$	$x^2(23) = 59.195$	$x^2(23) = 82.463$
	P-value = .000	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
ns = not significant at p>0.1

Figure 13. The errors in the characters /ฆ/ (Cho Chang) (Real words)

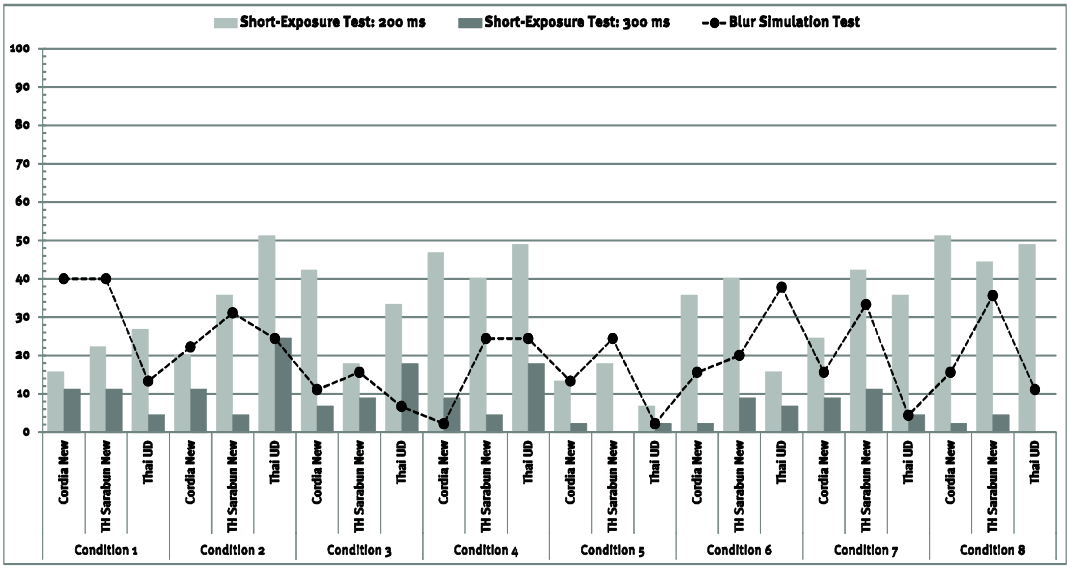


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 1	Cordia New	31.1 ns	13.3 ▽**	4.4 ns
	TH Sarabun New	17.8 ns	20 ▽*	6.7 ns
	Thai UD	6.7 ▽**	17.8 ▽**	2.2 ns
Condition 2	Cordia New	11.1 ▽*	24.4 ▽+	4.4 ns
	TH Sarabun New	44.4 ▲**	46.7 ns	17.8 ▲*
	Thai UD	17.8 ns	46.7 ns	17.8 ▲*
Condition 3	Cordia New	17.8 ns	8.9 ▽**	8.9 ns
	TH Sarabun New	35.6 ns	11.1 ▽**	8.9 ns
	Thai UD	2.2 ▽**	15.6 ▽**	0 ▽*
Condition 5	Cordia New	44.4 ▲**	60 ▲**	6.7 ns
	TH Sarabun New	55.6 ▲**	46.7 ns	6.7 ns
	Thai UD	20 ns	62.2 ▲**	4.4 ns
Condition 6	Cordia New	24.4 ns	80 ▲**	42.2 ▲**
	TH Sarabun New	46.7 ▲**	64.4 ▲**	4.4 ns
	Thai UD	64.4 ▲**	75.6 ▲**	11.1 ns
Condition 7	Cordia New	11.1 ▽*	35.6 ns	11.1 ns
	TH Sarabun New	28.9 ns	31.1 ns	2.2 ns
	Thai UD	6.7 ▽**	24.4 ▽+	0 ▽*

Chi-square	$\chi^2(17) = 126.899$	$\chi^2(17) = 171.979$	$\chi^2(17) = 90.000$
	P-value = .000	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 14. The errors in the characters /ช/ (Cho Chang) substituted the characters /ถ/ (Tho Thong)

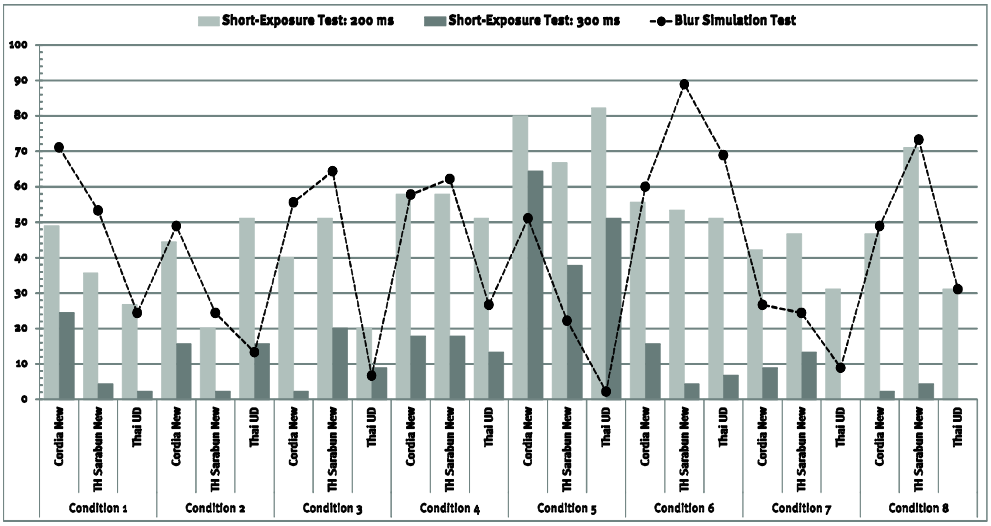


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 1	Cordia New	40▲**	15.6 ▽*	11.1 ns
	TH Sarabun New	40 ▲**	22.2 ns	11.1 ns
	Thai UD	13.3 ns	26.7 ns	4.4 ns
Condition 2	Cordia New	22.2 ns	20 ▽+	11.1 ns
	TH Sarabun New	31.1▲+	35.6 ns	4.4 ns
	Thai UD	24.4 ns	51.1▲**	24.4▲**
Condition 3	Cordia New	11.1 ns	42.2 ns	6.7 ns
	TH Sarabun New	15.6 ns	17.8 ▽*	8.9 ns
	Thai UD	6.7 ▽*	33.3 ns	17.8▲**
Condition 4	Cordia New	2.2 ▽**	46.7▲*	8.9 ns
	TH Sarabun New	24.4 ns	40 ns	4.4 ns
	Thai UD	24.4 ns	48.9▲*	17.8▲**
Condition 5	Cordia New	13.3 ns	13.3 ▽**	2.2 ns
	TH Sarabun New	24.4 ns	17.8 ▽*	0 ▽*
	Thai UD	2.2 ▽**	6.7 ▽**	2.2 ns
Condition 6	Cordia New	15.6 ns	35.6 ns	2.2 ns
	TH Sarabun New	20 ns	40 ns	8.9 ns
	Thai UD	37.8 ▲**	15.6 ▽*	6.7 ns
Condition 7	Cordia New	15.6 ns	24.4 ns	8.9 ns
	TH Sarabun New	33.3 ▲*	42.2 ns	11.1 ns
	Thai UD	4.4 ▽**	35.6 ns	4.4 ns
Condition 8	Cordia New	15.6 ns	51.1▲**	2.2 ns
	TH Sarabun New	35.6 ▲**	44.4▲+	4.4 ns
	Thai UD	11.1 ns	48.9▲*	0 ▽*

Chi-square	$x^2(23) = 87.151$	$x^2(23) = 88..591$	$x^2(23) = 52.609$
	P-value = .000	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

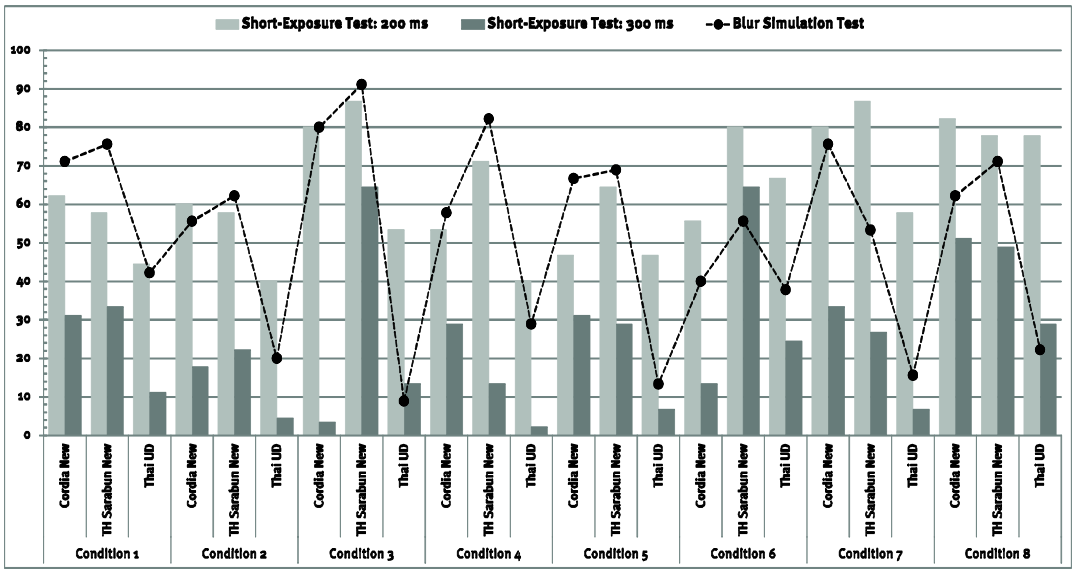
Figure 15. The errors in the characters /ช/ (Cho Chang) substituted the characters /ร/ (Ro Rua)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 1	Cordia New	71.1 ▲**	48.9 ns	24.4 ▲+
	TH Sarabun New	53.3 ns	35.6 ▽+	4.4 ▽*
	Thai UD	24.4 ▽*	26.7 ▽**	2.2 ▽*
Condition 2	Cordia New	48.9 ns	44.4 ns	15.6 ns
	TH Sarabun New	24.4 ▽*	20 ▽**	2.2▽ *
	Thai UD	13.3 ▽**	51.1 ns	15.6 ns
Condition 3	Cordia New	55.6 ▲+	40 ns	2.2 ▽*
	TH Sarabun New	64.4 ▲**	51.1 ns	20 ns
	Thai UD	6.7 ▽**	20 ▽**	8.9 ns
Condition 4	Cordia New	57.8 ▲*	57.8 ns	17.8 ns
	TH Sarabun New	62.2 ▲**	57.8 ns	17.8 ns
	Thai UD	26.7 ▽*	51.1 ns	13.3 ns
Condition 5	Cordia New	51.1 ns	80 ▲**	64.4 ▲**
	TH Sarabun New	22.2 ▽**	66.7 ▲*	37.8 ▲**
	Thai UD	2.2 ▽**	82.2 ▲**	51.1 ▲**
Condition 6	Cordia New	60 ▲*	55.6 ns	15.6 ns
	TH Sarabun New	88.9 ▲**	53.3 ns	4.4 ▽*
	Thai UD	68.9 ▲**	51.1 ns	6.7 ns
Condition 7	Cordia New	26.7 ▽*	42.2 ns	8.9 ns
	TH Sarabun New	24.4 ▽*	46.7 ns	13.3 ns
	Thai UD	8.9 ▽**	31.1 ▽*	0 ▽**
Condition 8	Cordia New	48.9 ns	46.7 ns	2.2 ▽*
	TH Sarabun New	73.3 ▲**	71.1 ▲**	4.4 ▽*
	Thai UD	31.1 ns	31.1 ▽*	0 ▽**
Chi-square		$x^2(23)$ =246.623	$x^2(23)$ = 112.641	$x^2(23)$ = 214.460
		P-value = .000	P-value = .000	P-value = .000
Significant Difference		Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 16. The errors in the characters /ช/ (Cho Chang) substituted the characters /ข/ (Kho Khai)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 1	Cordia New	71.1▲*	62.2 ns	31.1 ns
	TH Sarabun New	75.6 ▲**	57.8 ns	33.3 ns
	Thai UD	42.2 ns	44.4 ▽**	11.1 ▽*
Condition 2	Cordia New	55.6 ns	60 ns	17.8 ns
	TH Sarabun New	62.2 ns	57.8 ns	22.2 ns
	Thai UD	20 ▽**	40 ▽**	4.4 ▽**
Condition 3	Cordia New	80 ▲**	80 ▲*	3.3 ns
	TH Sarabun New	91.1▲**	86.7▲**	64.4▲**
	Thai UD	8.9 ▽**	53.3 ns	13.3 ▽*
Condition 4	Cordia New	57.8 ns	53.3 ns	28.9 ns
	TH Sarabun New	82.2 ▲**	71.1 ns	13.3 ▽*
	Thai UD	28.9 ▽**	40 ▽**	2.2 ▽**
Condition 5	Cordia New	66.7▲+	46.7 ▽*	31.1 ns
	TH Sarabun New	68.9▲*	64.4 ns	28.9 ns
	Thai UD	13.3 ▽**	46.7 ▽*	6.7 ▽**
Condition 6	Cordia New	40 ▽+	55.6 ns	13.3 ▽*
	TH Sarabun New	55.6 ns	80 ▲*	64.4▲**
	Thai UD	37.8 ▽*	66.7 ns	24.4 ns
Condition 7	Cordia New	75.6 ▲**	80 ▲*	33.3 ns
	TH Sarabun New	53.3 ns	86.7▲**	26.7 ns
	Thai UD	15.6 ▽**	57.8 ns	6.7 ▽**
Condition 8	Cordia New	62.2 ns	82.2▲**	51.1▲**
	TH Sarabun New	71.1▲*	77.8 ▲*	48.9 ▲**
	Thai UD	22.2 ▽**	77.8 ▲*	28.9 ns

Chi-square	$\chi^2(23) = 241.790$	$\chi^2(23) = 99.888$	$\chi^2(23) = 158.864$
	P-value = .000	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

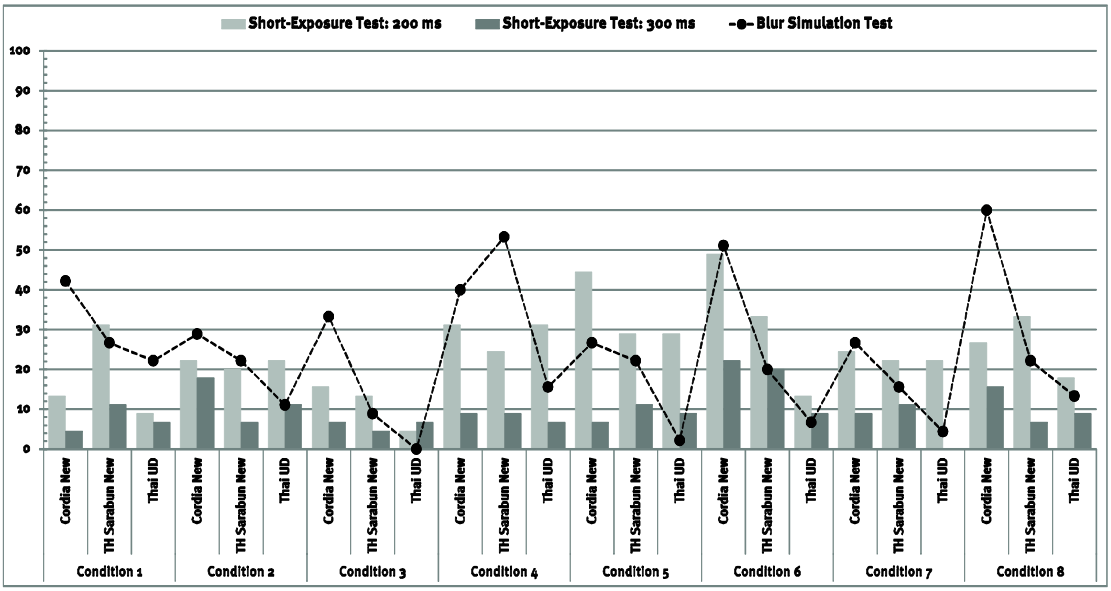
▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 17. The errors in the characters /ช/ (Cho Chang) substituted the characters /ซ/ (So So)

(4) The Characters /ซ/ (So So)

Real words: In the blur simulation test, the Thai UD font had reached the lowest incorrect response rate in every condition, and no error in condition 3. The rate of misreading did not exceed 10 in the 300-ms short-exposure test, and no error in the condition 7 (see Figure 18).

Pseudo words: The UD font has still obtained the lowest misidentification in the blur simulation test whereas in condition 6 (a word ‘มหาชัย’) revealed an error rate of more than 30%. Also, in 200-ms short-exposure test exhibited a few misreading rates in some conditions (e.g., the conditions 2, 3, 5, 6, and 8), while there was no incorrect response rate in the other conditions (e.g., the conditions 1, 4, and 7). In addition, the findings of the Thai UD font in the conditions 1, 3, and 4 with the 200-ms test had a lower misreading rate than the conventional text fonts, except in the other conditions which had an increased error rate, especially in the condition 6 and 7 (see Figure 19).

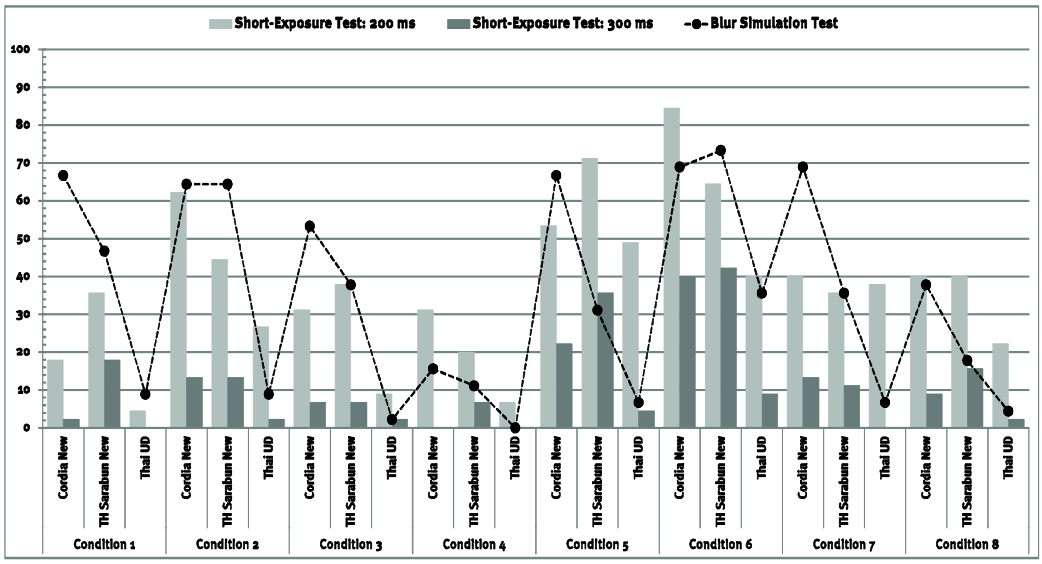


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 1	Cordia New	42.2 ▲**	13.3 ▽+	4.4
	TH Sarabun New	26.7 ns	31.1 ns	11.1
	Thai UD	22.2 ns	8.9 ▽*	6.7
Condition 2	Cordia New	28.9 ns	22.2 ns	17.8
	TH Sarabun New	22.2 ns	20 ns	6.7
	Thai UD	11.1 ▽*	22.2 ns	11.1
Condition 3	Cordia New	33.3 ns	15.6 ns	6.7
	TH Sarabun New	8.9 ▽*	13.3 ▽+	4.4
	Thai UD	0 ▽**	4.4 ▽**	6.7
Condition 4	Cordia New	40 ▲*	31.1 ns	8.9
	TH Sarabun New	53.3 ▲**	24.4 ns	8.9
	Thai UD	15.6 ns	31.1 ns	6.7
Condition 5	Cordia New	26.7 ns	44.4 ▲**	6.7
	TH Sarabun New	22.2 ns	28.9 ns	11.1
	Thai UD	2.2 ▽**	28.9 ns	8.9
Condition 6	Cordia New	51.1 ▲**	48.9 ▲**	22.2
	TH Sarabun New	20 ns	33.3 ns	20
	Thai UD	6.7 ▽**	13.3 ▽+	8.9
Condition 7	Cordia New	26.7 ns	24.4 ns	8.9
	TH Sarabun New	15.6 ns	22.2 ns	11.1
	Thai UD	4.4 ▽**	22.2 ns	0
Condition 8	Cordia New	60 ▲**	26.7 ns	15.6
	TH Sarabun New	22.2 ns	33.3 ns	6.7
	Thai UD	13.3 ▽+	17.8 ns	8.9

Chi-square	$x^2(23) = 148.709$	$x^2(23) = 61.419$	$x^2(23) = 30.641$
	P-value = .000	P-value = .000	P-value = .108
Significant Difference	Yes	Yes	No

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 18. The errors in the characters /ซ/ (So So) (Real words)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 1	Cordia New	66.7 ▲**	17.8 ▽**	2.2 ▽*
	TH Sarabun New	46.7 ▲+	35.6 ns	17.8 ns
	Thai UD	8.9 ▽**	4.4 ▽**	0 ▽*
Condition 2	Cordia New	64.4 ▲**	62.2 ▲**	13.3 ns
	TH Sarabun New	64.4 ▲**	44.4 ns	13.3 ns
	Thai UD	8.9 ▽**	26.7 ns	2.2 ▽*
Condition 3	Cordia New	53.3 ▲**	31.1 ns	6.7 ns
	TH Sarabun New	37.8 ns	37.8 ns	6.7 ns
	Thai UD	2.2 ▽**	8.9 ▽**	2.2 ▽*
Condition 4	Cordia New	15.6 ▽**	31.1 ns	0 ▽*
	TH Sarabun New	11.1 ▽**	20 ▽*	6.7 ns
	Thai UD	0 ▽**	6.7 ▽**	0 ▽*
Condition 5	Cordia New	66.7 ▲**	53.3 ▲*	22.2 ▲*
	TH Sarabun New	31.1 ns	71.1 ▲**	35.6 ▲**
	Thai UD	6.7 ▽**	48.9 ns	4.4 ns
Condition 6	Cordia New	68.9 ▲**	84.4 ▲**	40 ▲**
	TH Sarabun New	73.3 ▲**	64.4 ▲**	42.2 ▲**
	Thai UD	35.6 ns	40 ns	8.9 ns
Condition 7	Cordia New	68.9 ▲**	40 ns	13.3 ns
	TH Sarabun New	35.6 ns	35.6 ns	11.1 ns
	Thai UD	6.7 ▽**	37.8 ns	0 ▽*
Condition 8	Cordia New	37.8 ns	40 ns	8.9 ns
	TH Sarabun New	17.8 ▽*	40 ns	15.6 ns
	Thai UD	4.4 ▽**	22.2 ▽*	2.2 ▽*

Chi-square	$x^2(23) = 306.836$	$x^2(23) = 174.776$	$x^2(23) = 155.972$
	P-value = .000	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
ns = not significant at p>0.1

Figure 19. The errors in the characters /ซ/ (So So) substituted the characters /ช/ (Cho Chang)

(5) The Characters /ไ/ (Sara Ai Maimalai)

Real words: The Thai UD font words had the lowest misreading rate in the blur simulation test. However, in the conditions 5B (a word ‘อุปไนย’) and 5C (a word ‘ผู้ไทย’) obtained a significant incorrect response rate (see Figure 21). It is clear that a diagonal terminal of the character Sara Ai Maimalai /ไ/ which closed to an ascender of the character Po Pla /ป/ (condition 5B, อุปไนย) and Mai Tho ้/ (condition 5C, ผู้ไทย) caused visibility problems. To solve this defect, fine-tuning the space between the characters should be arranged. If possible, an aspect of a tail (terminal) of the character Sara Ai Maimalai /ไ/ may be improved in order to facilitate better visibility in this case (see Figure 20).

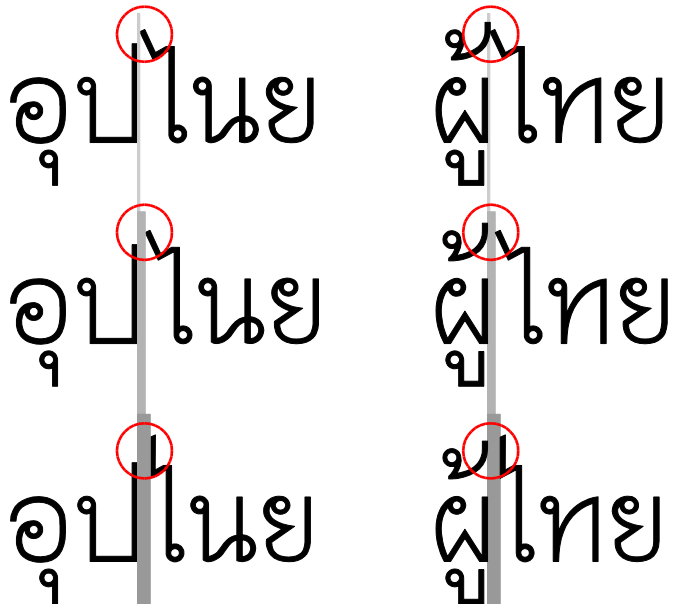
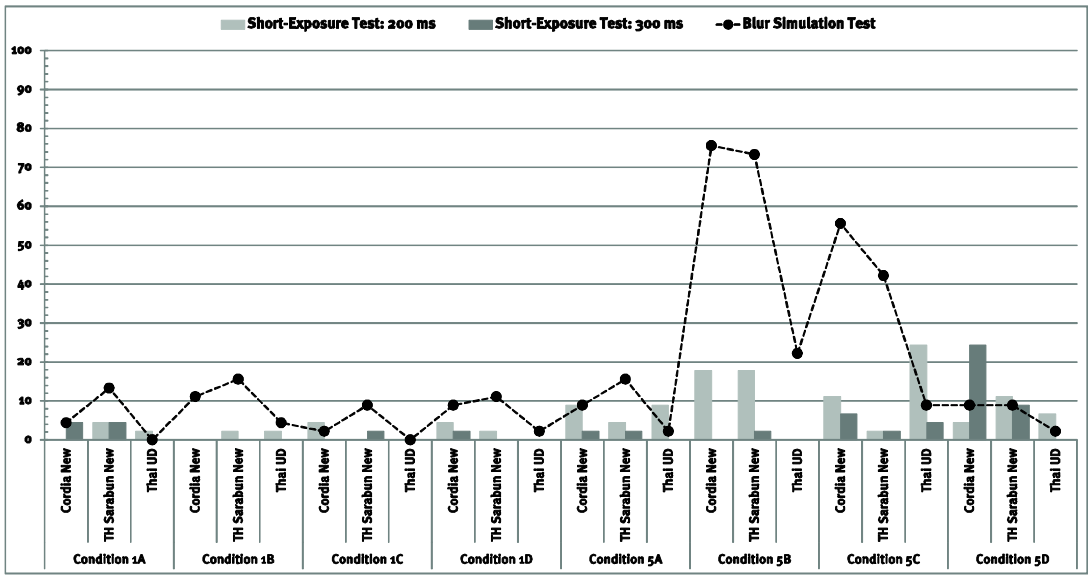


Figure 20. Middle: An example of improving inter-letter space of the character pairs Sara Ai Maimalai /ไ/ and upper-vowel (Mai Tho ้/). Lower: An approach to re-designing a glyph of Sara Ai Maimalai /ไ/.

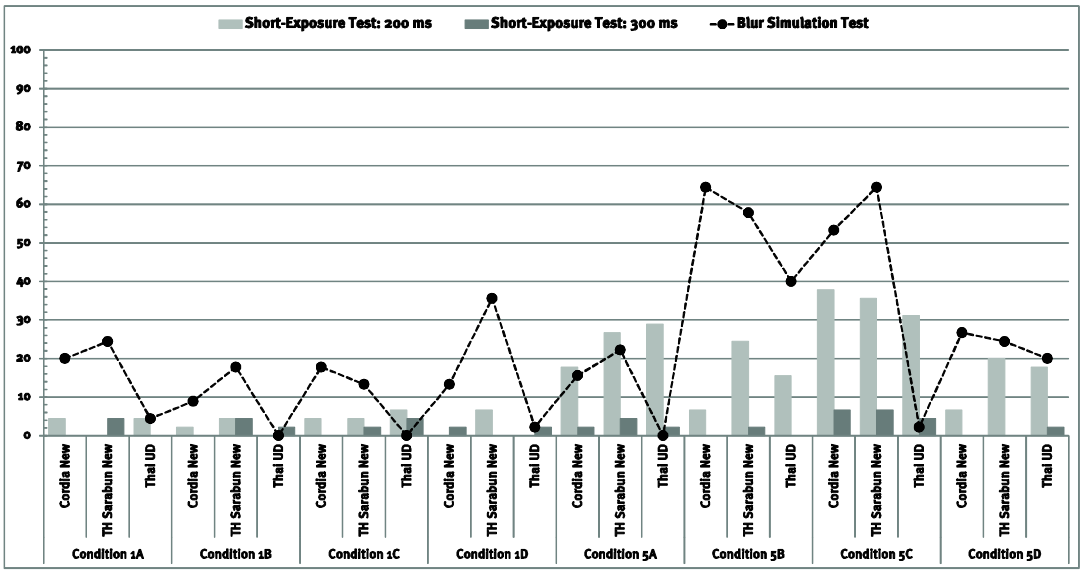


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 1A	Cordia New	4.4 ∇*	0 ∇+	4.4 ns
	TH Sarabun New	13.3 ns	4.4 ns	4.4 ns
	Thai UD	0 ∇**	2.2 ns	0 ns
Condition 1B	Cordia New	11.1 ns	0 ∇+	0 ns
	TH Sarabun New	15.6 ns	2.2 ns	0 ns
	Thai UD	4.4 ∇*	2.2 ns	0 ns
Condition 1C	Cordia New	2.2 ∇**	4.4 ns	0 ns
	TH Sarabun New	8.9 ns	0 ∇+	2.2 ns
	Thai UD	0 ∇**	0 ∇+	0 ns
Condition 1D	Cordia New	8.9 ns	4.4 ns	2.2 ns
	TH Sarabun New	11.1 ns	2.2 ns	0 ns
	Thai UD	2.2 ∇**	0 ∇+	0 ns
Condition 5A	Cordia New	8.9 ns	8.9 ns	2.2 ns
	TH Sarabun New	15.6 ns	4.4 ns	2.2 ns
	Thai UD	2.2 ∇**	8.9 ns	0 ns
Condition 5B	Cordia New	75.6 ▲**	17.8 ▲**	0 ns
	TH Sarabun New	73.3 ▲**	17.8 ▲**	2.2 ns
	Thai UD	22.2 ns	0 ∇+	0 ns
Condition 5C	Cordia New	55.6 ▲**	11.1 ns	6.7 ns
	TH Sarabun New	42.2 ▲**	2.2 ns	2.2 ns
	Thai UD	8.9 ns	24.4 ▲**	4.4 ns
Condition 5D	Cordia New	8.9 ns	4.4 ns	24.4 ▲**
	TH Sarabun New	8.9 ns	11.1 ns	8.9 ▲*
	Thai UD	2.2 ∇**	6.7 ns	0 ns

Chi-square	$x^2(23) = 351.750$	$x^2(23) = 80.759$	$x^2(23) = 104.091$
	P-value = .000	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
∇** Font's word(s) which had less errors than the other characters in each test, p<0.1.
∇* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ∇**).
∇+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ∇** and ∇*).
ns = not significant at p>0.1

Figure 21. The errors in the characters /ไ/ (Sara Ai Maimalai) (Real words)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 1A	Cordia New	20ns	4.4 ▽+	0
	TH Sarabun New	24.4 ns	0 ▽**	4.4
	Thai UD	4.4 ▽**	4.4 ▽+	0
Condition 1B	Cordia New	8.9 ▽*	2.2 ▽*	0
	TH Sarabun New	17.8 ns	4.4 ▽+	4.4
	Thai UD	0 ▽**	0 ▽**	2.2
Condition 1C	Cordia New	17.8 ns	4.4 ▽+	0
	TH Sarabun New	13.3 ns	4.4 ▽+	2.2
	Thai UD	0 ▽**	6.7 ns	4.4
Condition 1D	Cordia New	13.3 ns	0 ▽**	2.2
	TH Sarabun New	35.6 ▲*	6.7 ns	0
	Thai UD	2.2 ▽**	0 ▽**	2.2
Condition 5A	Cordia New	15.6 ns	17.8 ns	2.2
	TH Sarabun New	22.2 ns	26.7 ▲**	4.4
	Thai UD	0 ▽*	28.9 ▲**	2.2
Condition 5B	Cordia New	64.4 ▲**	6.7 ns	0
	TH Sarabun New	57.8 ▲**	24.4 ▲*	2.2
	Thai UD	40 ▲**	15.6 ns	0
Condition 5C	Cordia New	53.3 ▲**	37.8 ▲**	6.7
	TH Sarabun New	64.4 ▲**	35.6 ▲**	6.7
	Thai UD	2.2 ▽*	31.1 ▲**	4.4
Condition 5D	Cordia New	26.7 ns	6.7 ns	0
	TH Sarabun New	24.4 ns	20 ns	0
	Thai UD	20 ns	17.8 ns	2.2

Chi-square	$x^2(23) = 238.218$	$x^2(23) = 138.876$	$x^2(23) = 22.500$
	P-value = .000	P-value = .000	P-value = .233
Significant Difference	Yes	Yes	No

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 22. The errors in the characters /ฺ/ (Sara Ai Maimalai) substituted the characters /ฺ/ (Sara O)

Pseudo words: The results were similar to the findings of the real words. A word in condition 5B (a word ‘อุปไภค’) acquired high error rate caused by the tail (ascender) of the character Po Pla /ป/ approaching the tail terminal of the character Sara Ai Maimalai /ไ/, as well as an issue in condition 5D (a word ‘ขี้ไกง’) produced low visibility when the characters Sara Ii/ี/, Mai Tho /้/, and Sara Ai Maimalai /ไ/ were close together (see Figure 22)

(6) The Characters /โ/ (Sara O)

Real words: Most results of the Thai UD font had a lower misreading rate, sometimes having no error, whereas there was an incorrect response rate exceeding 10% in condition 5D (a word ‘ขี้โกง’) (see Figure 24). It seems likely that, the Thai UD font, a front part of the character Sara O /โ/ encountered with the character Sara Ii/ี/ caused visibility problems (see Figure 23).

Pseudo words: In the blur simulation test and 300-ms short-exposure test, the findings of the UD font indicated that had a lower misidentification and sometimes no error. In the 200-ms presentation, some conditions (e.g., the conditions 1B, 1C, 1D, and 5D) exhibited the amount of error lower than 10%, while the results in the other conditions (e.g., the conditions 1A, 5A, 5C, and 5D) had misreading rate exceed 10% (see Figure 25). Remark that the finding of a word ‘ผู้โทย’ in condition 5C may encounter the same issue with the result of the real word ‘ขี้โกง’ in condition 5D (see Figure 23).

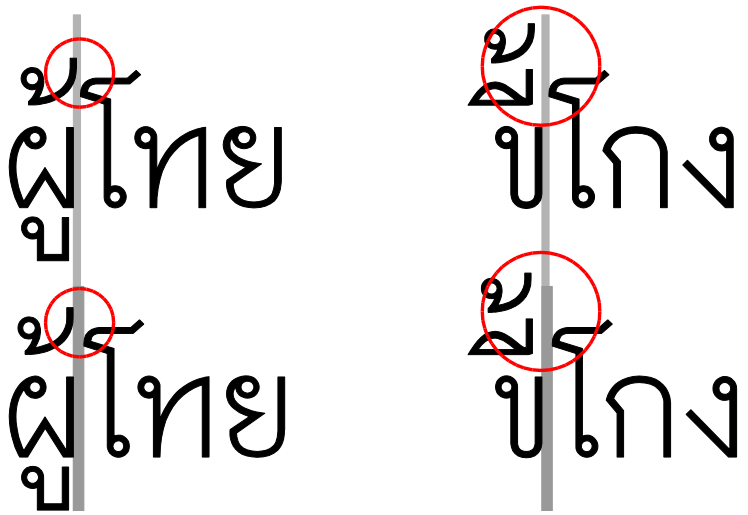
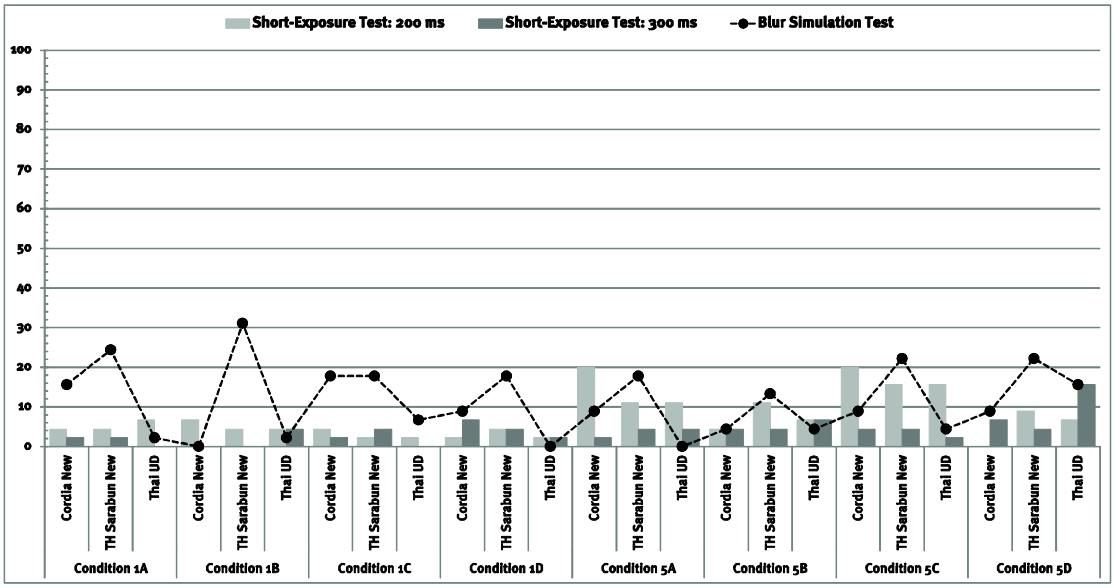


Figure 23. Visibility problems in words between the character pairs Sara O /โ/ - Mai Tho /้/ (left) and Sara O /โ/ - Sara Ii/ี/ (right)

(1) The Characters/ี/ (Sara Ii)

Real words: The findings of the UD font words in blur simulation test revealed a high misreading rate, particularly in the conditions 5F (a word 'ขี้ไคล') and 5G (a word 'แฮปปี้'). The results in the 300-ms short-exposure test exhibited no incorrect response in condition 5A (a word 'ผีทะเล') and had a slight misidentification rate in condition 5D (a word 'ผีโป่ง') (see Figure 26). A problem in the character Sara Ii /ี/ as a small letterform has involved the use in diminutive size along with an issue concerning some character with an ascending part which is placed near Sara Ii/ี/ (e.g., the character Sara O /โ/) or a letterform which has an ascender (e.g., the character Po Pla /ป/). These can cause visibility problems in low visual acuity conditions.

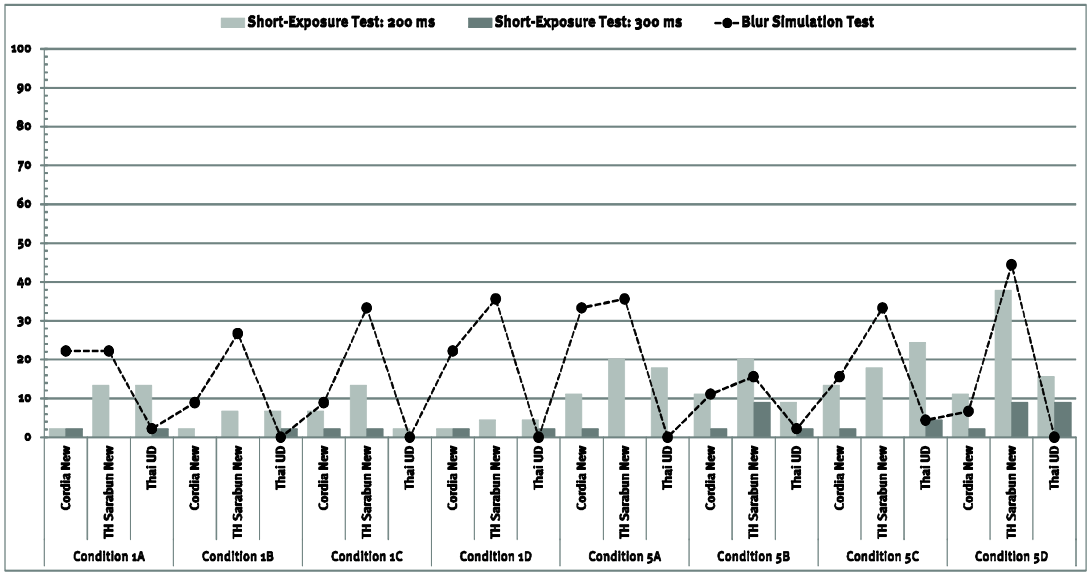


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 1A	Cordia New	15.6 ns	4.4 ns	2.2
	TH Sarabun New	24.4 ▲**	4.4 ns	2.2
	Thai UD	2.2 ▽*	6.7 ns	0
Condition 1B	Cordia New	0 ▽*	6.7 ns	0
	TH Sarabun New	31.1 ▲**	4.4 ns	0
	Thai UD	2.2 ▽*	4.4 ns	4.4
Condition 1C	Cordia New	17.8 ns	4.4 ns	2.2
	TH Sarabun New	17.8 ns	2.2 ns	4.4
	Thai UD	6.7 ns	2.2 ns	0
Condition 1D	Cordia New	8.9 ns	2.2 ns	6.7
	TH Sarabun New	17.8 ns	4.4 ns	4.4
	Thai UD	0 ▽*	2.2 ns	2.2
Condition 5A	Cordia New	8.9 ns	20 ▲**	2.2
	TH Sarabun New	17.8 ns	11.1 ns	4.4
	Thai UD	0 ▽*	11.1 ns	4.4
Condition 5B	Cordia New	4.4 ns	4.4 ▽**	4.4
	TH Sarabun New	13.3 ns	11.1 ns	4.4
	Thai UD	4.4 ns	6.7 ns	6.7
Condition 5C	Cordia New	8.9 ns	20 ▲**	4.4
	TH Sarabun New	22.2 ▲*	15.6 ▲*	4.4
	Thai UD	4.4 ns	15.6 ▲*	2.2
Condition 5D	Cordia New	8.9 ns	0 ▽+	6.7
	TH Sarabun New	22.2 ▲*	8.9 ns	4.4
	Thai UD	15.6 ns	6.7 ns	15.6

Chi-square	$x^2(23) = 77.257$	$x^2(23) = 46.647$	$x^2(23) = 28.836$
	P-value = .000	P-value = .004	P-value = .184
Significant Difference	Yes	Yes	No

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 24. The errors in the characters /ไ/ (Sara O) (Real words)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 1A	Cordia New	22.2 ns	2.2 ▽*	2.2 ns
	TH Sarabun New	22.2 ns	13.3 ns	0 ns
	Thai UD	2.2 ▽**	13.3 ns	2.2 ns
Condition 1B	Cordia New	8.9 ns	2.2 ▽*	0 ns
	TH Sarabun New	26.7 ▲*	6.7 ns	0 ns
	Thai UD	0 ▽**	6.7 ns	2.2 ns
Condition 1C	Cordia New	8.9 ns	6.7 ns	2.2 ns
	TH Sarabun New	33.3 ▲**	13.3 ns	2.2 ns
	Thai UD	0 ▽**	2.2 ▽*	0 ns
Condition 1D	Cordia New	22.2 ns	2.2 ▽*	2.2 ns
	TH Sarabun New	35.6 ▲**	4.4 ns	0 ns
	Thai UD	0 ▽**	4.4 ns	2.2 ns
Condition 5A	Cordia New	33.3 ▲**	11.1 ns	2.2 ns
	TH Sarabun New	35.6 ▲**	20 ▲+	0 ns
	Thai UD	0 ▽**	17.8 ns	0 ns
Condition 5B	Cordia New	11.1 ns	11.1 ns	2.2 ns
	TH Sarabun New	15.6 ns	20 ▲+	8.9 ▲**
	Thai UD	2.2 ▽**	8.9 ns	2.2 ns
Condition 5C	Cordia New	15.6 ns	13.3 ns	2.2 ns
	TH Sarabun New	33.3 ▲**	17.8 ns	0 ns
	Thai UD	4.4 ▽*	24.4 ▲**	4.4 ns
Condition 5D	Cordia New	6.7 ▽+	11.1 ns	2.2 ns
	TH Sarabun New	44.4 ▲**	37.8 ▲**	8.9 ▲**
	Thai UD	0 ▽**	15.6 ns	8.9 ▲**

Chi-square	$\chi^2(23) = 157.584$	$\chi^2(23) = 69.644$	$\chi^2(23) = 33.893$
	P-value = .000	P-value = .000	P-value = .086
Significant Difference	Yes	Yes	No

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

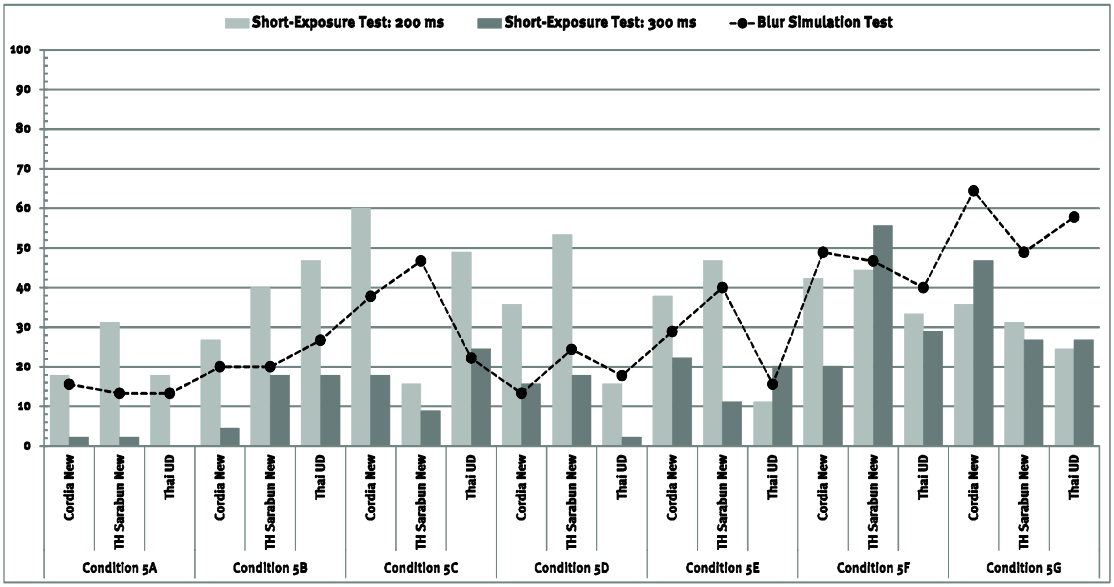
Figure 25. The errors in the characters /โ/ (Sara O) substituted the characters /ไ/ (Sara Ai Maimalai)

Pseudo words: Although the most results of the UD font in character Sara Ii /ี/ had positive findings better than the other fonts in the blur simulation test, the results in each condition produced innumerable misidentification rate. Also, including the findings in the short-exposure tests, especially in condition 5s when the character Sara Ii /ี/ met those tone marks such as the words ‘ขี้นรถ’, ‘ซื้อหา’, and so on (see Figure 27 and 28).

(2) The Characters /ึ/ (Sara Ue)

Real words: With the conditions 5A-5D, the incorrect response rate was moderate, whereas in the conditions 5E – 5G (e.g., the words ‘ขึ้นรถ’, ‘ซึ้งใจ’, and ‘ปั้นปึง’, respectively) revealed that had large misreading rates increased to exceed 50% (see Figure 29).

Pseudo words: The results exhibited a significant misidentification rate, more than the findings in the real words test (see Figure 30 and 31). Even though sometimes the UD font had a lower incorrect response rate than the conventional text fonts, it could not ensure in case of some words which had some characters encompass both in vertical and horizontal axis such as the words ‘ขี้ไคล’, ‘แฮปปี้’, ‘ขงจื้อ’, and so on.

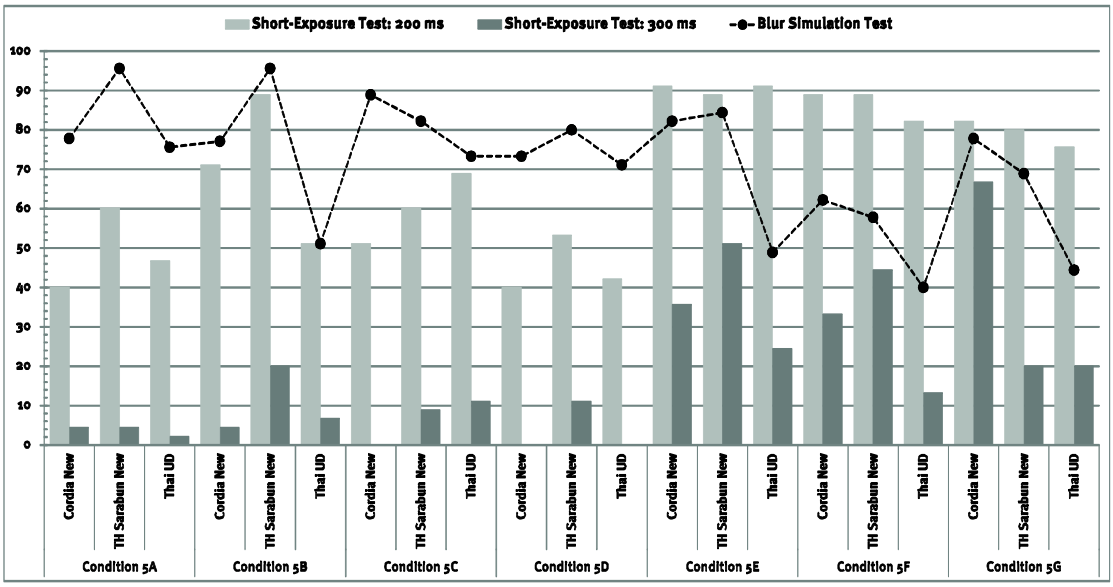


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	15.6 ▽*	17.8 ▽*	2.2 ▽**
	TH Sarabun New	13.3 ▽**	31.1 ns	2.2 ▽**
	Thai UD	13.3 ▽**	17.8 ▽*	0 ▽**
Condition 5B	Cordia New	20 ▽+	26.7 ns	4.4 ▽*
	TH Sarabun New	20 ▽+	40 ns	17.8 ns
	Thai UD	26.7 ns	46.7 ▲+	17.8 ns
Condition 5C	Cordia New	37.8 ns	60 ▲**	17.8 ns
	TH Sarabun New	46.7 ▲*	15.6 ▽**	8.9 ▽+
	Thai UD	22.2 ns	48.9 ▲*	24.4 ns
Condition 5D	Cordia New	13.3 ▽**	35.6 ns	15.6 ns
	TH Sarabun New	24.4 ns	53.3 ▲**	17.8 ns
	Thai UD	17.8 ▽*	15.6 ▽**	2.2 ▽**
Condition 5E	Cordia New	28.9 ns	37.8 ns	22.2 ns
	TH Sarabun New	40 ns	46.7 ▲+	11.1 ns
	Thai UD	15.6 ▽*	11.1 ▽**	20 ns
Condition 5F	Cordia New	48.9 ▲*	42.2 ns	20 ns
	TH Sarabun New	46.7 ▲*	44.4 ns	55.6 ▲**
	Thai UD	40 ns	33.3 ns	28.9 ▲+
Condition 5G	Cordia New	64.4 ▲**	35.6 ns	46.7 ▲**
	TH Sarabun New	48.9 ▲*	31.1 ns	26.7 ns
	Thai UD	57.8 ▲**	24.4 ns	26.7 ns

Chi-square	$\chi^2(20) = 107.172$	$\chi^2(20) = 74.458$	$\chi^2(20) = 117.916$
	P-value = .000	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 26. The errors in the characters ี/ (Sara Ii) (Real words)

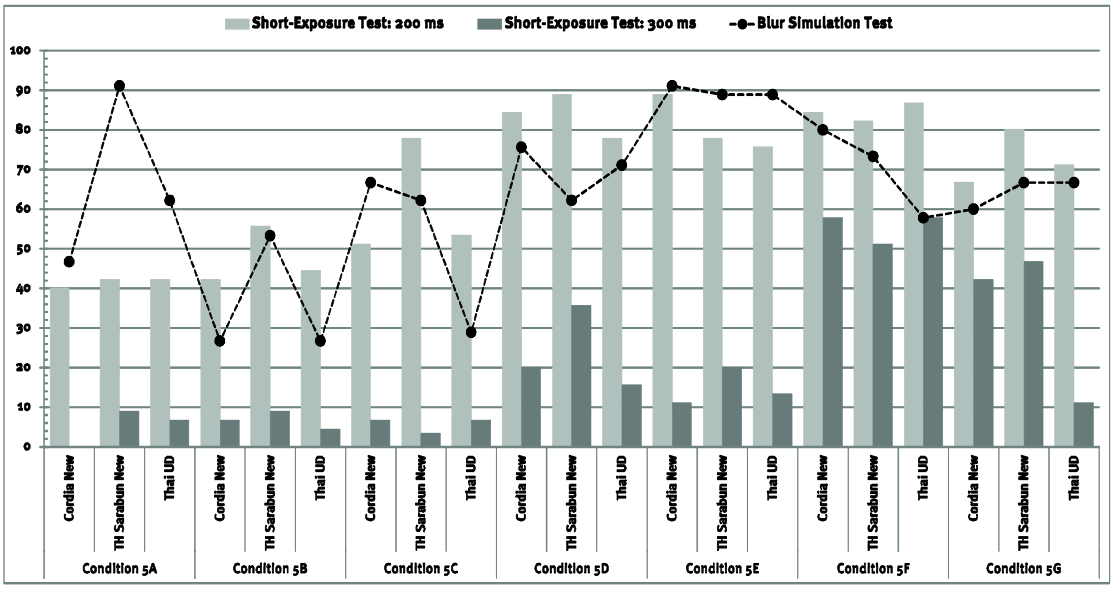


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	77.8 ns	40 ▽**	4.4 ▽*
	TH Sarabun New	95.6 ▲**	60 ns	4.4 ▽*
	Thai UD	75.6 ns	46.7 ▽**	2.2 ▽**
Condition 5B	Cordia New	77.1 ns	71.1 ns	4.4 ▽*
	TH Sarabun New	95.6 ▲**	88.9 ▲**	20 ns
	Thai UD	51.1 ▽**	51.1 ▽**	6.7 ▽*
Condition 5C	Cordia New	88.9 ▲**	51.1 ▽**	0 ▽**
	TH Sarabun New	82.2 ns	60 ns	8.9 ▽+
	Thai UD	73.3 ns	68.9 ns	11.1 ns
Condition 5D	Cordia New	73.3 ns	40 ▽**	0 ▽**
	TH Sarabun New	80 ns	53.3 ▽*	11.1 ns
	Thai UD	71.1 ns	42.2 ▽**	0 ▽**
Condition 5E	Cordia New	82.2 ns	91.1 ▲**	35.6 ▲**
	TH Sarabun New	84.4 ▲*	88.9 ▲**	51.1 ▲**
	Thai UD	48.9 ▽**	91.1 ▲**	24.4 ns
Condition 5F	Cordia New	62.2 ns	88.9 ▲**	33.3 ▲**
	TH Sarabun New	57.8 ▽*	88.9 ▲**	44.4 ▲**
	Thai UD	40 ▽**	82.2 ▲*	13.3 ns
Condition 5G	Cordia New	77.8 ns	82.2 ▲*	66.7 ▲**
	TH Sarabun New	68.9 ns	80 ▲+	20 ns
	Thai UD	44.4 ▽**	75.6 ns	20 ns

Chi-square	$\chi^2(20) = 109.704$	$\chi^2(20) = 146.878$	$\chi^2(20) = 207.358$
	P-value = .000	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

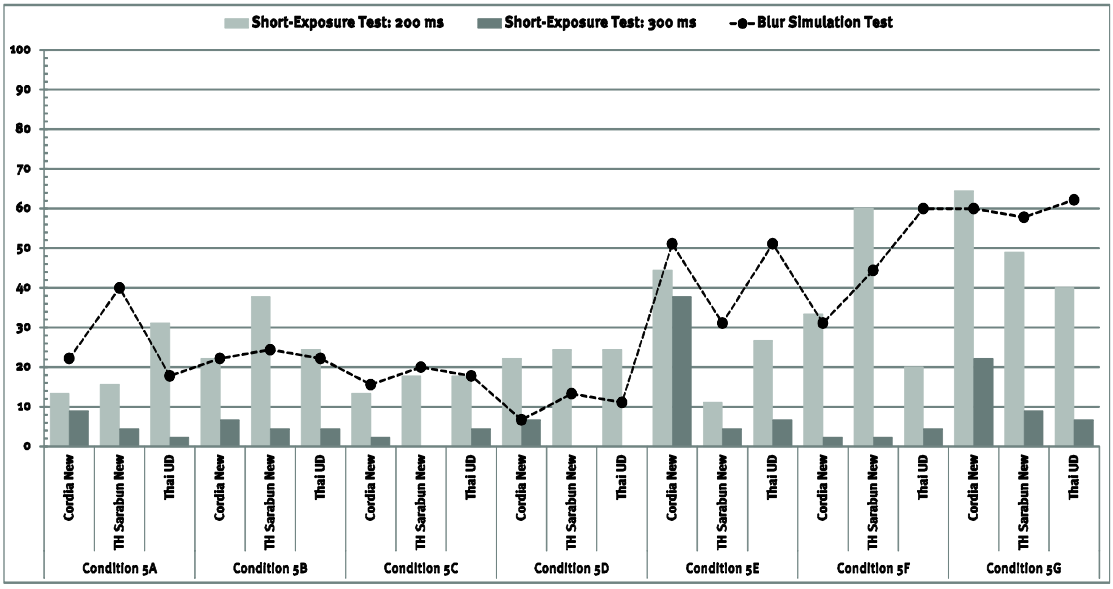
Figure 27. The errors in the characters◌ี/ (Sara Ii) substituted the characters◌ู/ (Sara Ue)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	46.7 ▽*	40 ▽**	0 ▽**
	TH Sarabun New	91.1 ▲**	42.2 ▽**	8.9 ▽*
	Thai UD	62.2 ns	42.2 ▽**	6.7 ▽*
Condition 5B	Cordia New	26.7 ▽**	42.2 ▽**	6.7 ▽*
	TH Sarabun New	53.3 ns	55.6 ▽+	8.9 ▽*
	Thai UD	26.7 ▽**	44.4 ▽**	4.4 ▽**
Condition 5C	Cordia New	66.7 ns	51.1 ▽*	6.7 ▽*
	TH Sarabun New	62.2 ns	77.8 ns	3.3 ns
	Thai UD	28.9 ▽**	53.3 ▽*	6.7 ▽*
Condition 5D	Cordia New	75.6 ns	84.4 ▲*	20 ns
	TH Sarabun New	62.2 ns	88.9 ▲**	35.6 ▲*
	Thai UD	71.1 ns	77.8 ns	15.6 ns
Condition 5E	Cordia New	91.1 ▲**	88.9 ▲**	11.1 ▽+
	TH Sarabun New	88.9 ▲**	77.8 ns	20 ns
	Thai UD	88.9 ▲**	75.6 ns	13.3 ns
Condition 5F	Cordia New	80 ▲*	84.4 ▲*	57.8 ▲**
	TH Sarabun New	73.3 ns	82.2 ▲*	51.1 ▲**
	Thai UD	57.8 ns	86.7 ▲**	57.8 ▲**
Condition 5G	Cordia New	60 ns	66.7 ns	42.2 ▲**
	TH Sarabun New	66.7 ns	80 ▲+	46.7 ▲**
	Thai UD	66.7 ns	71.1 ns	11.1 ▽+
Chi-square		$\chi^2(20) = 151.718$	$\chi^2(20) = 131.707$	$\chi^2(20) = 191.689$
		P-value = .000	P-value = .000	P-value = .000
Significant Difference		Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

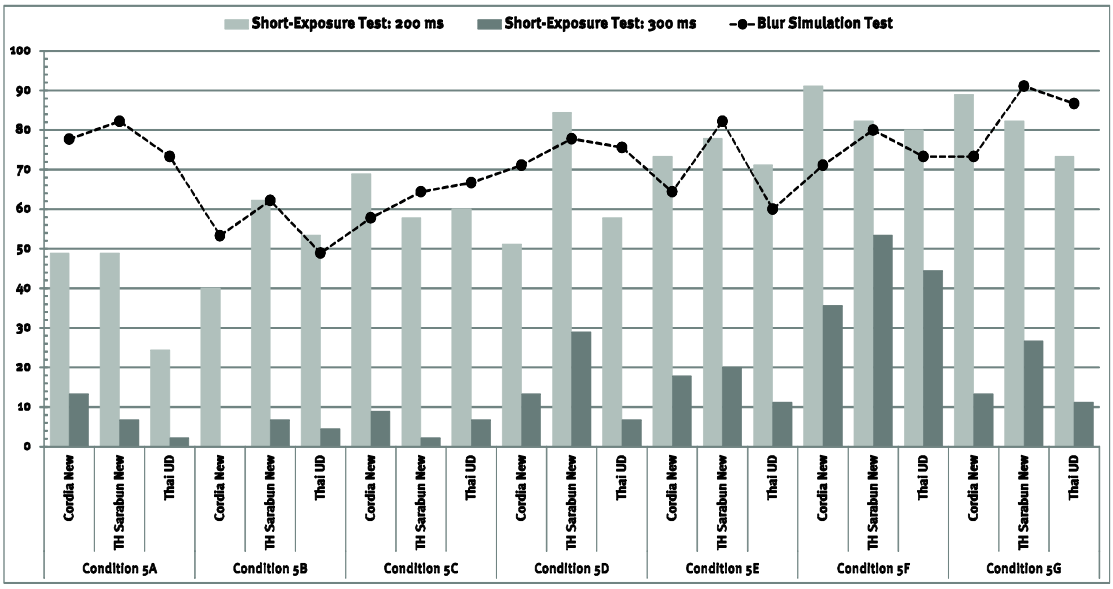
Figure 28. The errors in the characters ◌ี/ (Sara Ii) substituted the characters ◌ี/ (Sara Uee)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	22.2 ns	13.3 ▽*	8.9 ns
	TH Sarabun New	40 ns	15.6 ▽*	4.4 ns
	Thai UD	17.8 ▽*	31.1 ns	2.2 ns
Condition 5B	Cordia New	22.2 ns	22.2 ns	6.7 ns
	TH Sarabun New	24.4 ns	37.8 ns	4.4 ns
	Thai UD	22.2 ns	24.4 ns	4.4 ns
Condition 5C	Cordia New	15.6 ▽*	13.3 ▽*	2.2 ns
	TH Sarabun New	20 ▽+	17.8 ▽+	0 ▽+
	Thai UD	17.8 ▽*	17.8 ▽+	4.4 ns
Condition 5D	Cordia New	6.7 ▽**	22.2 ns	6.7 ns
	TH Sarabun New	13.3 ▽**	24.4 ns	0 ▽+
	Thai UD	11.1 ▽**	24.4 ns	0 ▽+
Condition 5E	Cordia New	51.1 ▲**	44.4 ▲*	37.8 ▲**
	TH Sarabun New	31.1 ns	11.1 **	4.4 ns
	Thai UD	51.1 ▲**	26.7 ns	6.7 ns
Condition 5F	Cordia New	31.1 ns	33.3 ns	2.2 ns
	TH Sarabun New	44.4 ▲+	60 ▲**	2.2 ns
	Thai UD	60 ▲**	20 ns	4.4 ns
Condition 5G	Cordia New	60 ▲**	64.4 ▲**	22.2 ▲**
	TH Sarabun New	57.8 ▲**	48.9 ▲**	8.9 ns
	Thai UD	62.2 ▲**	40 ns	6.7 ns
Chi-square		$\chi^2(20) = 137.080$	$\chi^2(20) = 99.155$	$\chi^2(20) = 105.714$
		P-value = .000	P-value = .000	P-value = .000
Significant Difference		Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 29. The errors in the characters ◌ั/ (Sara Ue) (Real words)

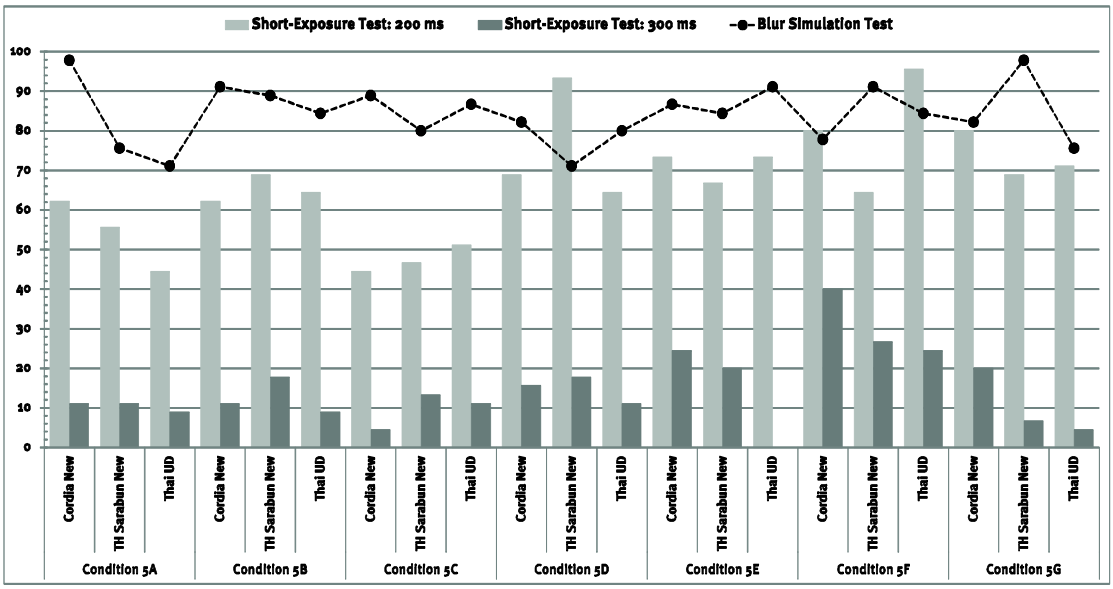


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	77.7 ns	48.9 ▽*	13.3 ns
	TH Sarabun New	82.2 ▲+	48.9 ▽*	6.7 ▽+
	Thai UD	73.3 ns	24.4 ▽**	2.2 ▽*
Condition 5B	Cordia New	53.3 ▽**	40 ▽**	0 ▽**
	TH Sarabun New	62.2 ns	62.2 ns	6.7 ▽+
	Thai UD	48.9 ▽**	53.3 ▽+	4.4 ▽*
Condition 5C	Cordia New	57.8 ▽*	68.9 ns	8.9 ns
	TH Sarabun New	64.4 ns	57.8 ns	2.2 ▽*
	Thai UD	66.7 ns	60 ns	6.7 ▽+
Condition 5D	Cordia New	71.1 ns	51.1 *	13.3 ns
	TH Sarabun New	77.8 ns	84.4 ▲**	28.9 ▲*
	Thai UD	75.6 ns	57.8 ns	6.7 ▽+
Condition 5E	Cordia New	64.4 ns	73.3 ns	17.8 ns
	TH Sarabun New	82.2 ▲+	77.8 ▲+	20 ns
	Thai UD	60 ▽+	71.1 ns	11.1 ns
Condition 5F	Cordia New	71.1 ns	91.1 ▲**	35.6 ▲**
	TH Sarabun New	80 ns	82.2 ▲*	53.3 ▲**
	Thai UD	73.3 ns	80 ▲*	44.4 ▲**
Condition 5G	Cordia New	73.3 ns	88.9 ▲**	13.3 ns
	TH Sarabun New	91.1 ▲**	82.2 ▲*	26.7 ▲*
	Thai UD	86.7 ▲*	73.3 ns	11.1 ns

Chi-square	$\chi^2(20) = 52.356$	$\chi^2(20) = 120.669$	$\chi^2(20) = 138.885$
	P-value = .000	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 30. The error in the characters◌ั/ (Sara Ue) substituted the characters◌ี/ (Sara Ii)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	97.8 ▲*	62.2 ns	11.1 ns
	TH Sarabun New	75.6 ns	55.6 ns	11.1 ns
	Thai UD	71.1 ▽*	44.4 ▽**	8.9 ns
Condition 5B	Cordia New	91.1 ns	62.2 ns	11.1 ns
	TH Sarabun New	88.9 ns	68.9 ns	17.8 ns
	Thai UD	84.4 ns	64.4 ns	8.9 ns
Condition 5C	Cordia New	88.9 ns	44.4 ▽**	4.4 ▽*
	TH Sarabun New	80 ns	46.7 ▽**	13.3 ns
	Thai UD	86.7 ns	51.1 ▽*	11.1 ns
Condition 5D	Cordia New	82.2 ns	68.9 ns	15.6 ns
	TH Sarabun New	71.1 ▽*	93.3 ▲**	17.8 ns
	Thai UD	80 ns	64.4 ns	11.1 ns
Condition 5E	Cordia New	86.7 ns	73.3 ns	24.4 ▲+
	TH Sarabun New	84.4 ns	66.7 ns	20 ns
	Thai UD	91.1 ns	73.3 ns	0 ▽**
Condition 5F	Cordia New	77.8 ns	80 ▲+	40 ▲**
	TH Sarabun New	91.1 ns	64.4 ns	26.7 ▲*
	Thai UD	84.4 ns	95.6 ▲**	24.4 ▲+
Condition 5G	Cordia New	82.2 ns	80 ▲+	20 ns
	TH Sarabun New	97.8 ▲*	68.9 ns	6.7 ns
	Thai UD	75.6 ns	71.1 ns	4.4 ▽*

Chi-square	$x^2(20) = 38.787$	$x^2(20) = 77.600$	$x^2(20) = 60.040$
	P-value = .002	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
ns = not significant at p>0.1

Figure 31. The errors in the characters ◌ี/ (Sara Ue) substituted the characters ◌ี/ (Sara Uee)

(3) The Characters ◌ี/ (Sara Uee)

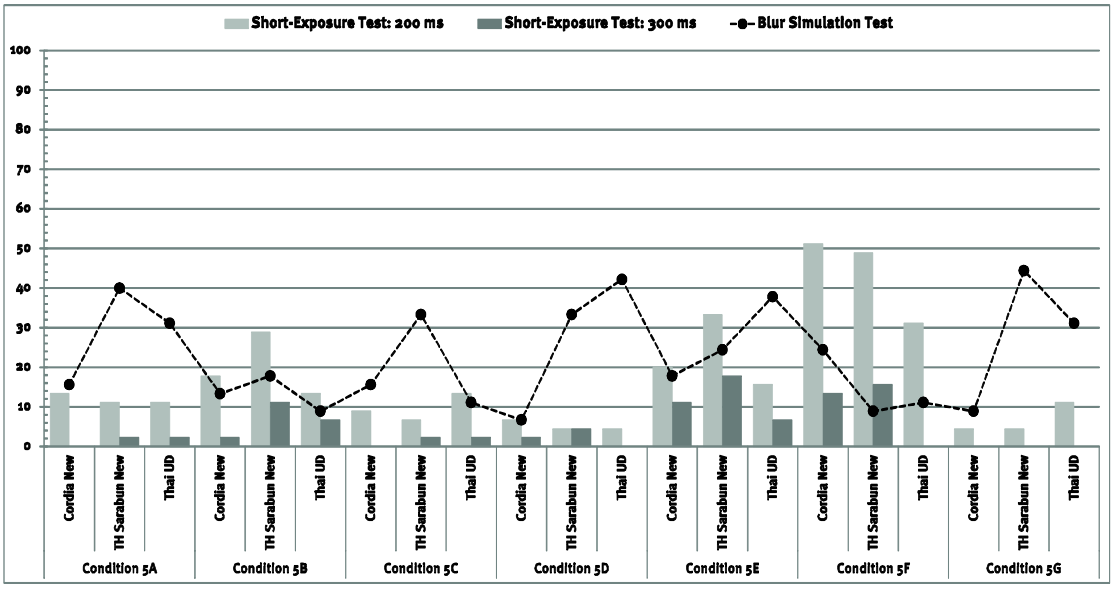
Real words: In the blur simulation test, the words ‘ขงจี้อ’ and ‘ยกพื้น’ in the conditions 5D and 5E, respectively, obtained the highest misreading rate (see Figure 32).

Pseudo words: Almost finding produced inordinate incorrect response rate, especially the results in blur simulation test (see Figure 33 and 34). Same as the problem in Sara Ue ◌ี/ and Sara Ii ◌ี/, an encounter of a tone mark and upper vowel may cause visibility problem. It is necessary to provide sufficient inter-letter space in order to distinguish each character easily.

(4) The Characters ◌้/ (Mai Han-akat)

Real words: The results suggest that having excessive tight inter-letter space between Sara Ii ◌ี/ and Mai Han-akut ◌้/ in a word ‘ที่รัก’ (condition 5F) caused low visibility problems. However, with an appropriate inter-letter spacing in the word ‘อาบัติ’ (condition 5G) visibility is enhanced (see Figure 35).

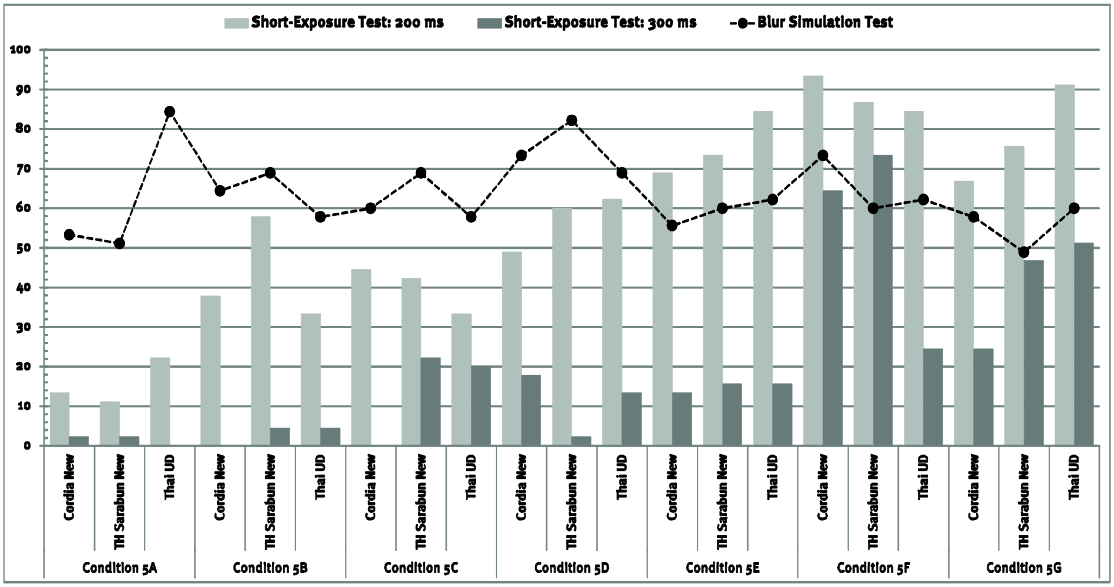
Pseudo words: In case of the character Mai Han-akut ◌้/ substituted Mai Tho ◌้/ (see Figure 36), the findings of the UD font indicated that had the lowest misreading rate in the blur simulation test but the error rates exceeded 50%, while the findings in the short-exposure tests, the results of each font exhibited the amount of incorrect response rate equally.



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	15.6 ns	13.3 ns	0 ns
	TH Sarabun New	40 ▲**	11.1 ns	2.2 ns
	Thai UD	31.1 ns	11.1 ns	2.2 ns
Condition 5B	Cordia New	13.3 ns	17.8 ns	2.2 ns
	TH Sarabun New	17.8 ns	28.9 ▲*	11.1 ▲*
	Thai UD	8.9 ▽*	13.3 ns	6.7 ns
Condition 5C	Cordia New	15.6 ns	8.9 ns	0 ns
	TH Sarabun New	33.3 ▲+	6.7 ▽+	2.2 ns
	Thai UD	11.1 ▽+	13.3 ns	2.2 ns
Condition 5D	Cordia New	6.7 ▽**	6.7 ▽+	2.2 ns
	TH Sarabun New	33.3 ▲+	4.4 ▽*	4.4 ns
	Thai UD	42.2 ▲**	4.4 ▽*	0 ns
Condition 5E	Cordia New	17.8 ns	20 ns	11.1 ▲*
	TH Sarabun New	24.4 ns	33.3 ▲**	17.8 ▲**
	Thai UD	37.8 ▲*	15.6 ns	6.7 ns
Condition 5F	Cordia New	24.4 ns	51.1 ▲**	13.3 ▲**
	TH Sarabun New	8.9 ▽*	48.9 ▲**	15.6 ▲**
	Thai UD	11.1 ▽+	31.1 ▲*	0 ns
Condition 5G	Cordia New	8.9 ▽*	4.4 ▽*	0 ns
	TH Sarabun New	44.4 ▲**	4.4 ▽*	0 ns
	Thai UD	31.1 ns	11.1 ns	0 ns
Chi-square		$\chi^2(20) = 79.128$	$\chi^2(20) = 122.075$	$\chi^2(20) = 63.980$
		P-value = .000	P-value = .000	P-value = .000
Significant Difference		Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 32. The errors in the characters ◌ั/ (Sara Uee) (Real words)

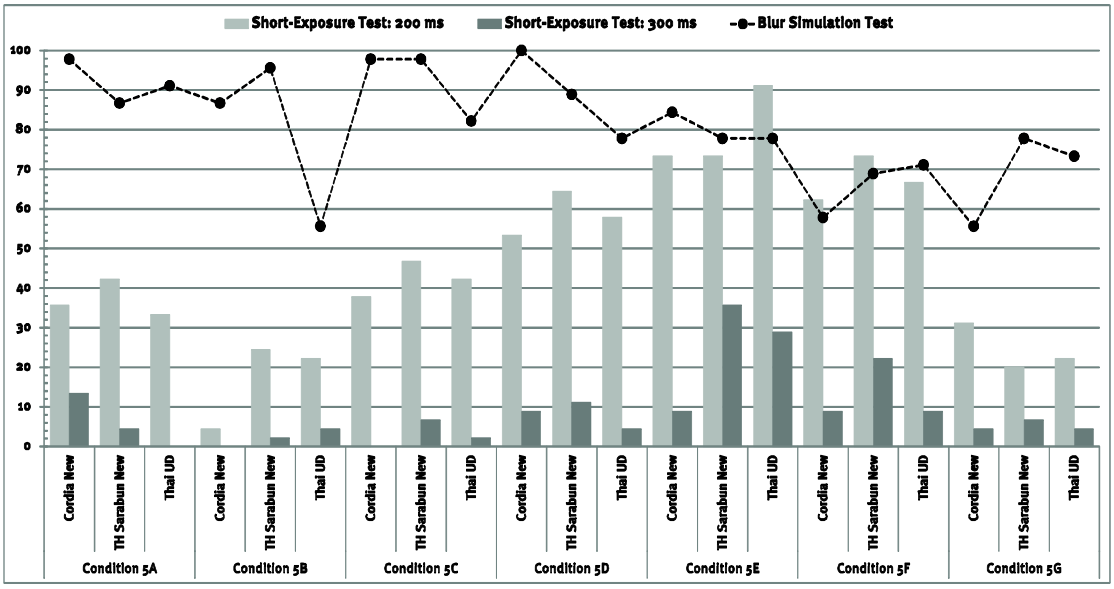


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	53.3 ns	13.3 ▽**	2.2 ▽**
	TH Sarabun New	51.1 ▽+	11.1 ▽**	2.2 ▽**
	Thai UD	84.4 ▲**	22.2 ▽**	0 ▽**
Condition 5B	Cordia New	64.4 ns	37.8 ▽**	0 ▽**
	TH Sarabun New	68.9 ns	57.8 ns	4.4 ▽**
	Thai UD	57.8 ns	33.3 ▽**	4.4 ▽**
Condition 5C	Cordia New	60 ns	44.4 ▽+	0 ▽**
	TH Sarabun New	68.9 ns	42.2 ▽*	22.2 ns
	Thai UD	57.8 ns	33.3 ▽**	20 ns
Condition 5D	Cordia New	73.3 ns	48.9 ns	17.8 ns
	TH Sarabun New	82.2 ▲**	60 ns	2.2 ns
	Thai UD	68.9 ns	62.2 ns	13.3 ns
Condition 5E	Cordia New	55.6 ns	68.9 ▲+	13.3 ns
	TH Sarabun New	60 ns	73.3 ▲*	15.6 ns
	Thai UD	62.2 ns	84.4 ▲**	15.6 ns
Condition 5F	Cordia New	73.3 ns	93.3 ▲**	64.4 ▲**
	TH Sarabun New	60 ns	86.7 ▲**	73.3 ▲**
	Thai UD	62.2 ns	84.4 ▲**	24.4 ns
Condition 5G	Cordia New	57.8 ns	66.7 ns	24.4 ns
	TH Sarabun New	48.9 ▽*	75.6 ▲**	46.7 ▲**
	Thai UD	60 ns	91.1 ▲**	51.1 ▲**

Chi-square	$x^2(20) = 34.015$	$x^2(20) = 236.560$	$x^2(20) = 244.965$
	P-value = .016	P-value = .000	P-value = .000
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

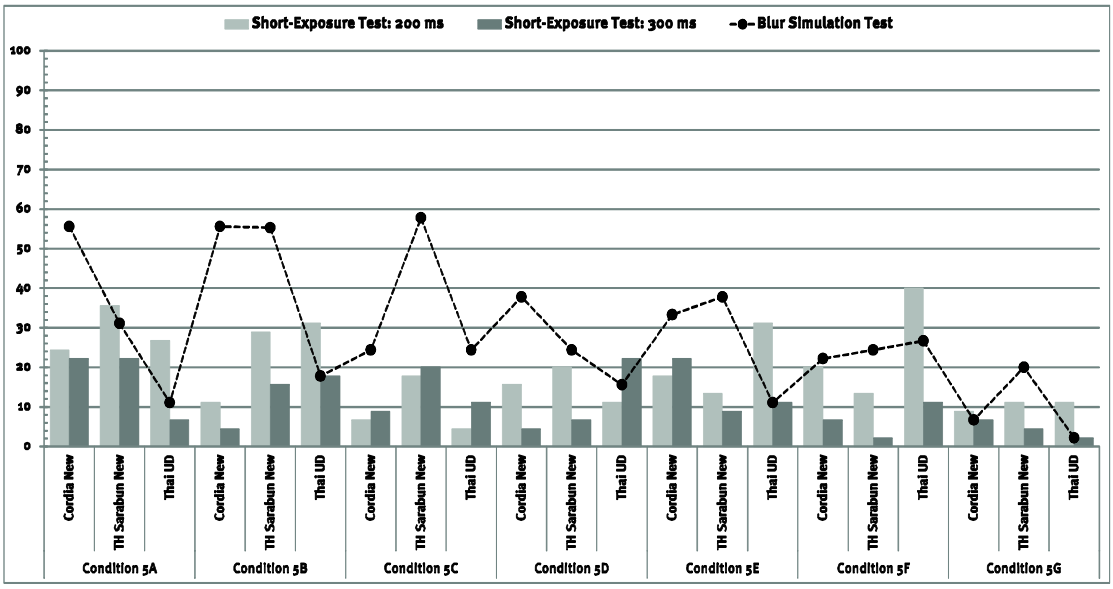
Figure 33. The errors in the characters ◌ั/ (Sara Uee) substituted the characters ◌ั/ (Sara Ii)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	97.8 ▲**	35.6 ns	13.3 ns
	TH Sarabun New	86.7 ns	42.2 ns	4.4 ns
	Thai UD	91.1 ▲+	33.3 ▽+	0 ▽*
Condition 5B	Cordia New	86.7 ns	4.4 ▽**	0 ▽*
	TH Sarabun New	95.6 ▲*	24.4 ▽**	2.2 ns
	Thai UD	55.6 ▽**	22.2 ▽**	4.4 ns
Condition 5C	Cordia New	97.8 ▲**	37.8 ns	0 ▽*
	TH Sarabun New	97.8 ▲**	46.7 ns	6.7 ns
	Thai UD	82.2 ns	42.2 ns	2.2 ns
Condition 5D	Cordia New	100 ▲**	53.3 ns	8.9 ns
	TH Sarabun New	88.9 ns	64.4 ▲*	11.1 ns
	Thai UD	77.8 ns	57.8 ns	4.4 ns
Condition 5E	Cordia New	84.4 ns	73.3 ▲**	8.9 ns
	TH Sarabun New	77.8 ns	73.3 ▲**	35.6 ▲**
	Thai UD	77.8 ns	91.1 ▲**	28.9 ▲**
Condition 5F	Cordia New	57.8 ▽**	62.2 ▲*	8.9 ns
	TH Sarabun New	68.9 ▽*	73.3 ▲**	22.2 ▲**
	Thai UD	71.1 ▽+	66.7 ▲**	8.9 ns
Condition 5G	Cordia New	55.6 ▽**	31.1 ▽*	4.4 ns
	TH Sarabun New	77.8 ns	20 ▽**	6.7 ns
	Thai UD	73.3 ns	22.2 ▽**	4.4 ns
Chi-square		$\chi^2(20) = 112.492$	$\chi^2(20) = 182.280$	$\chi^2(20) = 97.134$
		P-value = .000	P-value = .000	P-value = .000
Significant Difference		Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 34. The errors in the characters◌ี◌ู (Sara Uee) substituted the characters◌ี◌ู (Sara Ue)

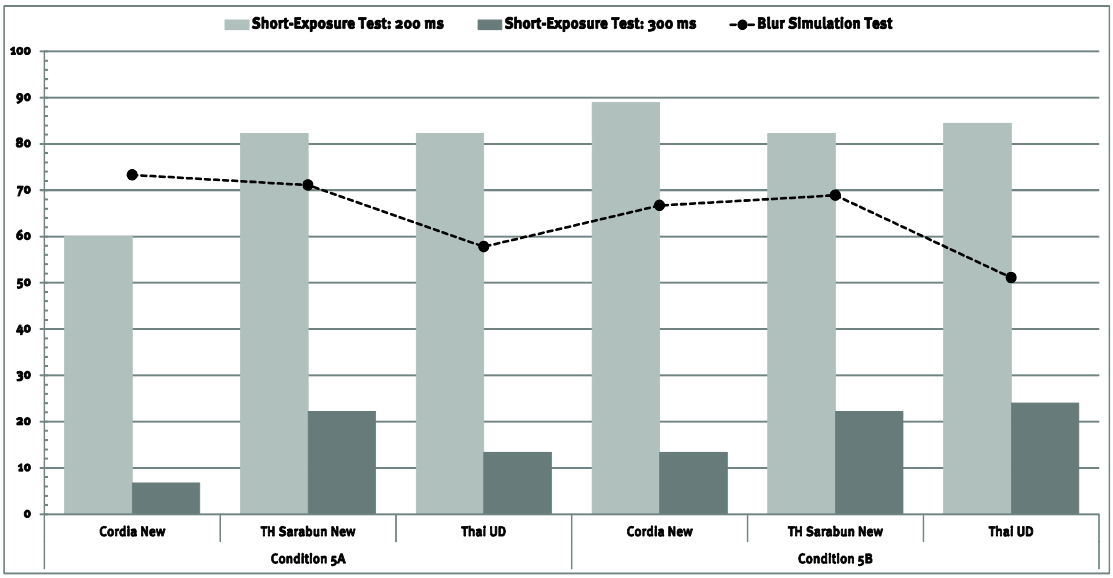


Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	55.6 ▲**	24.4 ns	22.2 ▲*
	TH Sarabun New	31.1 ns	35.6 ▲**	22.2 ▲*
	Thai UD	11.1 ▽**	26.7 ns	6.7 ns
Condition 5B	Cordia New	55.6 ▲**	11.1 ns	4.4 ns
	TH Sarabun New	55.3 ▲**	28.9 ▲+	15.6 ns
	Thai UD	17.8 ns	31.1 ▲*	17.8 ns
Condition 5C	Cordia New	24.4 ns	6.7 ▽*	8.9 ns
	TH Sarabun New	57.8 ▲**	17.8 ns	20 ▲+
	Thai UD	24.4 ns	4.4 ▽*	11.1 ns
Condition 5D	Cordia New	37.8 ns	15.6 ns	4.4 ns
	TH Sarabun New	24.4 ns	20 ns	6.7 ns
	Thai UD	15.6 ▽+	11.1 ns	22.2 ▲*
Condition 5E	Cordia New	33.3 ns	17.8 ns	22.2 ▲*
	TH Sarabun New	37.8 ns	13.3 ns	8.9 ns
	Thai UD	11.1 ▽**	31.1 ▲*	11.1 ns
Condition 5F	Cordia New	22.2 ns	20 ns	6.7 ns
	TH Sarabun New	24.4 ns	13.3 ns	2.2 ▽*
	Thai UD	26.7 ns	40 ▲**	11.1 ns
Condition 5G	Cordia New	6.7 ▽**	8.9 ▽+	6.7 ns
	TH Sarabun New	20 ns	11.1 ns	4.4 ns
	Thai UD	2.2 ▽**	11.1 ns	2.2 ▽*

Chi-square	$\chi^2(20) = 119.303$	$\chi^2(20) = 58.100$	$\chi^2(20) = 45.550$
	P-value = .000	P-value = .000	P-value = .001
Significant Difference	Yes	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲* Font's word(s) which had more errors than the other characters in each test, p<0.5 (except ▲**).
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲** and ▲*).
▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5 (except ▽**).
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽** and ▽*).
ns = not significant at p>0.1

Figure 35. The errors in the characters ◌̌/ (Mai Han-akat) (Real words)



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	73.3	60 ▽**	6.7
	TH Sarabun New	71.1	82.2 ns	22.2
	Thai UD	57.8	82.2 ns	13.3
Condition 5B	Cordia New	66.7	88.9 ns	13.3
	TH Sarabun New	68.9	82.2 ns	22.2
	Thai UD	51.1	84.4 ns	24

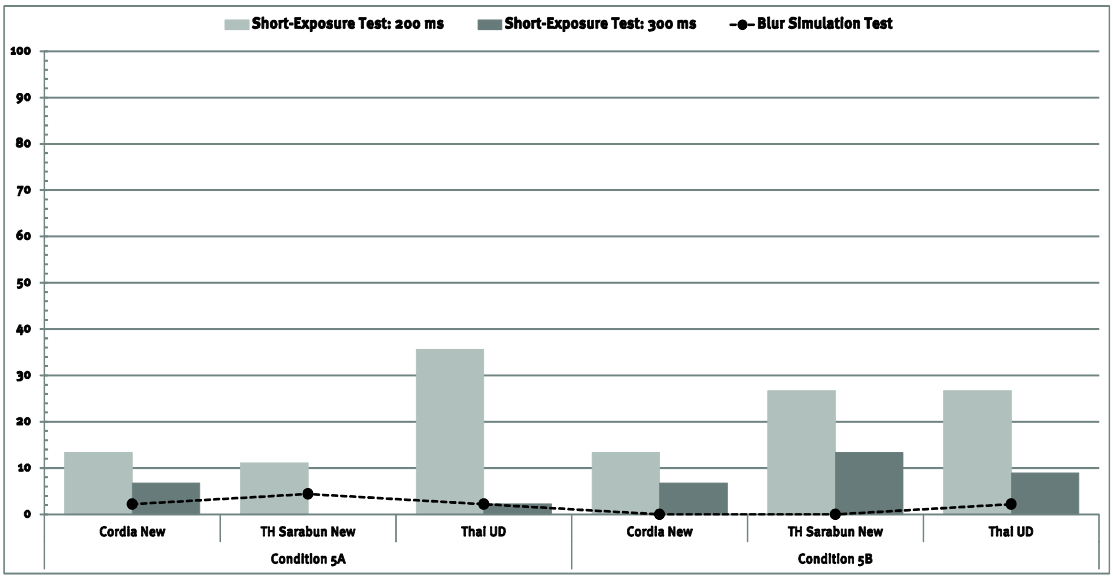
Chi-square	$x^2(5) = 7.292$	$x^2(5) = 14.444$	$x^2(5) = 7.756$
	P-value = .206	P-value = .023	P-value = .137
Significant Difference	No	Yes	No

▽** Font's word(s) which had less errors than the other characters in each test, p<0.1.
ns = not significant at p>0.1

Figure 36. The errors in the characters ้/ (Mai Han-akat) substituted the characters ้/ (Mai Tho)

(5) The Characters ้/ (Mai Tho)

Real words: In the blur simulation test and the 300-ms test, the tested words of each font had equally lower misidentification rates, while the findings of the UD font in the short-exposure test revealed incorrect response rates rather than the results of the conventional text fonts (see Figure 37).



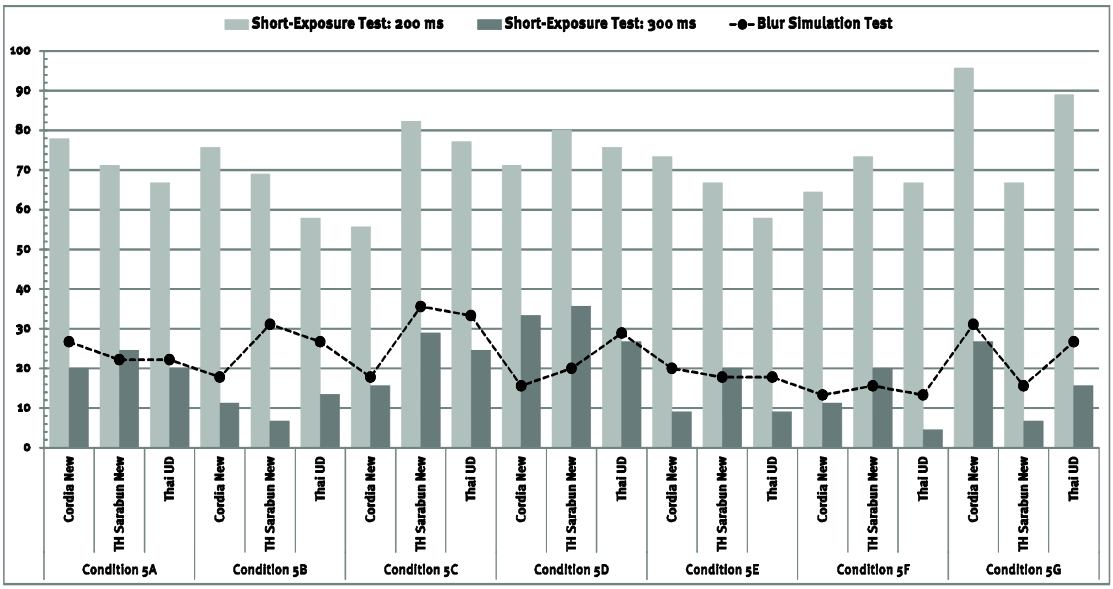
Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	2.2	13.3 ns	6.7
	TH Sarabun New	4.4	11.1 ▽+	0
	Thai UD	2.2	35.6 ▲**	2.2
Condition 5B	Cordia New	0	13.3 ns	6.7
	TH Sarabun New	0	26.7 ns	13.3
	Thai UD	2.2	26.7 ns	8.9

Chi-square	$x^2(5) = 3.464$	$x^2(5) = 13.277$	$x^2(5) = 8.600$
	P-value = .459	P-value = .021	P-value = .053
Significant Difference	No	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10.
ns = not significant at p>0.1

Figure 37. The errors in the characters ้/ (Mai Tho) (Real words)

Pseudo words: the findings of the UD font in the blur simulation test has misreading rates equal to the results of the conventional text fonts, yet sometimes revealed exceeding error rates. In the short-exposure test, each font produced inordinate misidentification rates, evident in the 200-ms presentation (see Figure 38).



Condition	Font	Amount of Error (%)		
		Blur Simulation Test	Short-Exposure Test: 200 ms	Short-Exposure Test: 300 ms
Condition 5A	Cordia New	26.7	77.8 ns	20 ns
	TH Sarabun New	22.2	71.1 ns	24.4 ns
	Thai UD	22.2	66.7 ns	20 ns
Condition 5B	Cordia New	17.8	75.6 ns	11.1 ns
	TH Sarabun New	31.1	68.9 ns	6.7 ▽*
	Thai UD	26.7	57.8 ▽*	13.3 ns
Condition 5C	Cordia New	17.8	55.6 ▽*	15.6 ns
	TH Sarabun New	35.6	82.2 ns	28.9 ▲+
	Thai UD	33.3	77.1 ns	24.4 ns
Condition 5D	Cordia New	15.6	71.1 ns	33.3 ▲**
	TH Sarabun New	20	80 ns	35.6 ▲**
	Thai UD	28.9	75.6 ns	26.7 ns
Condition 5E	Cordia New	20	73.3 ns	8.9 ▽+
	TH Sarabun New	17.8	66.7 ns	20 ns
	Thai UD	17.8	57.8 ▽*	8.9 ▽+
Condition 5F	Cordia New	13.3	64.4 ns	11.1 ns
	TH Sarabun New	15.6	73.3 ns	20 ns
	Thai UD	13.3	66.7 ns	4.4 ▽*
Condition 5G	Cordia New	31.1	95.6 ▲**	26.7 ns
	TH Sarabun New	15.6	66.7 ns	6.7 ▽*
	Thai UD	26.7	88.9 ▲**	15.6 ns

Chi-square	$\chi^2(20) = 24.468$	$\chi^2(20) = 42.785$	$\chi^2(20) = 49.739$
	P-value = .233	P-value = .000	P-value = .000
Significant Difference	No	Yes	Yes

▲** Font's word(s) which had more errors than the other characters in each test, p<0.1.
▲+ Font's word(s) which had more errors than the other characters in each test, p<.10 (except ▲**).
▽* Font's word(s) which had less errors than the other characters in each test, p<0.5.
▽+ Font's word(s) which had less errors than the other characters in each test, p<.10 (except ▽*).
ns = not significant at p>0.1

Figure 38. The characters ้/ (Mai Tho) substituted the characters ้/ (Mai Han-akat)

The results reflect that obtaining a significant misreading rate for the Thai UD font may also involve legibility in character Mai Tho ้. Enhancing the obviousness of a left-apex along with decreasing broadness of character width in Mai Tho ้ could improve legibility (see Figure 39).

Figure 39. Approach to improving a letterform of character Mai Tho ้

5 Conclusion

In order to prove the performance of the Thai UD font on visual word recognition, the final study employed a blur simulation method and a short-exposure method for measuring the effectiveness of the Thai characters with the real words and pseudo words, compared with the Thai conventional text fonts. Not only did this study involve clearness of the characters, but it also related to inter-letter space which influences visibility matters.

The results revealed that overall effectiveness on low visual acuity conditions of the Thai UD font has advantage over the conventional text fonts. However, the findings suggest that providing sufficient inter-letter space with specific particular character pairs may enhance better visibility, especially in those letterforms which have jutted out parts (e.g., a tail, a terminal, and a loop-with-serrated-line). In other words, the characters which have a jutting part (e.g., a second-loop, a loop-with-serrated-line, and a diagonal tail) should be defined with particular sufficient inter-letter space (tracking) when they encounter with the characters which possess tight letterform or include a jutting part.

Importantly, determining vertical inter-letter space of consonants with upper-vowels and lower vowels could improve visibility in conditions of low visual acuity although this way may impact the size of Bo Baimai height.

Moreover, the current study suggests that increasing character width in the characters with ascender (e.g., So So /ศ/) to contribute those upper-vowels (e.g., Sara Ii ◌ี/, Sara Ue◌ี/, Sara Uee◌ี/, and Mai Han-akat ◌ั/) and tone marks (e.g., Mai Tho ◌้/) which can enlarge their sizes.

The present study elucidates the role of distinctive letterforms and determines how suitable inter-letter space can influence blurred Thai words. Poor legibility and visibility affect not only the elderly readers but also the visually impaired, people with poor vision, as well as those learning to read Thai. Therefore, improving legibility (letter features) and visibility (space) of the Thai font is of great significance for a good quality of life. This awareness will invite the communities of design scholars and practitioners and encourage the participation of the cross-disciplinary field of experience design and wellbeing-centric design that connects communication design and typography with other fields, including social science, vision science, psychology, health sciences, etc.

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Appendix: Lists of Real Words and Pseudo Words

(Only the words of the selected results)

	1. Do Chada	Confused Pair (Pseudo word)		
	First Letter	ฏ	ภ	ฤ
Condition 2	ฏีกา	ฏีกา	No word	No word
	Within Word	ฏ	No word	No word
Condition 5A	กฏหมาย	กฏหมา	No word	No word
Condition 5B	กุฏาคาร	กุฏาคา	No word	No word
Condition 6	ดุษฎี	ดุษฏี	No word	No word

	2. To Patak	Confused Pair (Pseudo word)
	First Letter	ฏ
Condition 2	ฏังการ	ฏังการ
	Within Word	ฏ
Condition 5A	นาฏศิลป์	นาฏศิลป์
Condition 5B	ปรากฏ	ปรากฏ
Condition 6	ปฏิบัติ	ปฏิบัติ

	3. Cho Chang	Confused Pair (Pseudo word)	
	First Letter	ซ	ข
Condition 1	ซราภาพ	ซราภาพ	ขราภาพ
Condition 2	ซัยนาท	ซัยนาท	ขัยนาท
Condition 3	ซูพงษ์	ซูพงษ์	ขูพงษ์
Condition 4	ซุ่มคอ	ซุ่มคอ	ขุ่มคอ
	Within Word	ซ	ข
Condition 5	บรรพซน	บรรพซน	บรรพขน
Condition 6	มหาซัย	มหาซัย	มหาขัย

Condition 7	อรซุน	อรซุน	อรขุน
Condition 8	บุญซุ่ม	บุญซุ่ม	บุญขุ่ม

4. So So /ซ/	Confused Pair (Pseudo word)

	First Letter	ช	ข	ฆ
Condition 1	ซอยตัน	ชอยตัน	ขอยตัน	ฆอยตัน
Condition 2	ซักฟอก	ชักฟอก	ขักฟอก	ฆักฟอก
Condition 3	ซุปเปอร์	ชุปเปอร์	ขุปเปอร์	ฆุบเปอร์
Condition 4	ซุ้มกาแฟ	ชุ้มกาแ	ขุ้มกาแ	ฆุ้มกาแ

	Within Word	ช	ข	ฆ
Condition 5	อเมซอน	อเมชอน	อเมขอน	อเมฆอน
Condition 6	รูดซิป	รูดชิป	รูดขิป	รูดฆิป
Condition 7	น้ำซุป	น้ำชุป	น้ำขุป	น้ำฆุป
Condition 8	ลอดซุ้ม	ลอดชุ้ม	ลอดขุ้ม	ลอดฆุ้ม

5. Sara Ai Maimalai	Confused Pair (Pseudo word)

	First Letter	ใ	โ
Condition 1A	ไทยรัฐ	ใทยรัฐ	โทยรัฐ
Condition 1B	ไมยราพ	ใมยราพ	โมยราพ
Condition 1C	ไชยชนะ	ใชยชนะ	โชยชนะ
Condition 1D	ไวพจน์	ใวพจน์	โวพจน์

	Within Word	ใ	โ
Condition 5A	ตรงไหน	ตรงใหน	ตรงโหน
Condition 5B	อุปไนย	อุปในย	อุปโนย
Condition 5C	ผู้ไทย	ผู้ใทย	ผู้โทย
Condition 5D	ขี้ไคล	ขี้ใคล	ขี้โคล

6. Sara O	Confused Pair (Pseudo word)

	First Letter	ใ	ไ
Condition 1A	โถส้วม	ใถส้วม	ไถส้วม
Condition 1B	โชคลาภ	ใชคลาภ	ไชคลาภ

Condition 1C	โฆษณา	ใฆษณา	ไฆษณา
Condition 1D	โฉมงาม	ใฉมงาม	ไฉมงาม

	Within Word	ใ	ไ
Condition 5A	ผสมโรง	ผสมใรง	ผสมไรง
Condition 5B	อุปโภค	อุปใภค	อุปไภค
Condition 5C	ตรีโกณ	ตรีใกณ	ตรีไกณ
Condition 5D	ขี้โกง	ขี้ใกง	ขี้ไกง

	7. Sara Ii◌ี/	Confused Pair (Pseudo word)

	Within Word	◌ั	◌ิ	◌ี	◌ะ	◌็
Condition 5A	ผีทะเล	ผัทะเล	ผีทะเ	ผีทะเ	ผิทะเ	ผ็ทะเล
Condition 5B	ที่สาม	No Word	ที่สาม	ที่สาม	ที่สาม	No Word
Condition 5C	ซี่กรง	No Word	ซี่กรง	ซี่กรง	ซี่กรง	No Word
Condition 5D	ผีโป่ง	ผัโป่ง	ผีโป่ง	ผีโป่ง	ผิโป่ง	ผ็โป่ง
Condition 5E	ขี้บ่น	No Word	ขี้บ่น	ขี้บ่น	ขี้บ่น	No Word
Condition 5F	ขี้ไคล	No Word	ขี้ไคล	ขี้ไคล	ขี้ไคล	No Word
Condition 5G	แฮปปี้	No Word	แฮป	แฮป	แฮป	No Word

	8. Sara Ue◌ึ/	Confused Pair (Pseudo word)

	Within Word	◌ึ	◌ั	◌ะ	◌ึ	◌็
Condition 5A	ตกผลึก	ตกผลี	ตกผลั๊ก	ตกผลิ	ตกผลึ	ตกผล็ก
Condition 5B	ฮึดฮัด	ฮีดฮัด	ฮั๊ดฮัด	ฮิดฮัด	ฮึดฮัด	ฮ็ดฮัด
Condition 5C	ข้าศึก	ข้าศีก	ข้าศั๊ก	ข้าศิก	ข้าศึก	ข้าศ็ก
Condition 5D	รู้สึก	รู้สีก	รู้สั๊ก	รู้สิก	รู้สึก	รู้ส็ก
Condition 5E	ขึ้นรถ	ขี้นรถ	No Word	ขิ้นรถ	ขึ้นรถ	No Word
Condition 5F	ซึ้งใจ	ซี้งใจ	No Word	ซิ้งใจ	ซึ้งใจ	No Word
Condition 5G	ปั้นปึง	ปั้นปีง	ปั้นปั๊ง	ปั้นปิง	ปั้นปึง	ปั้นป็ง

	9. Sara Uee◌ื/	Confused Pair (Pseudo word)

	Within Word	◌ี	◌ึ	◌ั	◌ะ	◌็
Condition 5A	ถือหาง	ถีอหาง	ถึอหาง	ถั๊อหาง	ถิอหาง	ถ็อหาง

Condition 5B	ขาดมือ	ขาดมือ	ขาดมือ	ขาดม๊อ	ขาดมิอ	ขาดม็อ
Condition 5C	สืบเสาะ	สืบเสาะ	สืบเสาะ	ส๊บเสาะ	สิบเสาะ	ส็บเสาะ
Condition 5D	ขงจื๊อ	ขงจื้อ	ขงจื้อ	No Word	ขงจิ้อ	No Word
Condition 5E	ยกพื้น	ยกพื้น	ยกพื้น	No Word	ยกพิ้น	No Word
Condition 5F	ซื้อหา	ซื้อหา	ซื้อหา	No Word	ซิ้อหา	No Word
Condition 5G	อาวุธปืน	อาวุธปืน	อาวุธปื	อาวุธป๊น	อาวุธปิ	อาวุธป็น

	10. Mai Han-akat ไม้หันอากาศ	Confused Pair (Pseudo word)		
	Within Word	้	๊	็
Condition 5A	ตัวแปร	ต้วแปร	ต๊วแปร	ต็วแปร
Condition 5B	ผ่าตัด	ผ่าต้ด	ผ่าต๊ด	ผ่าต็ด
Condition 5C	สัญญาณ	ส้ญญา	ส๊ญญา	ส็ญญา
Condition 5D	มหาชัย	มหาช้ย	มหาช๊ย	มหาช็ย
Condition 5E	ฮัลโหล	ฮ้ลโหล	ฮ๊ลโหล	ฮ็ลโหล
Condition 5F	ที่รัก	ที่ร้ก	ที่ร๊ก	ที่ร็ก
Condition 5G	อาบัติ	อาบ้ติ	อาบ๊ติ	อาบ็ติ

	11. Mai Tho ไม้โท	Confused Pair (Pseudo word)		
	Within Word	้	๊	็
Condition 5A	การค้นหา	การคันห	การค๊นห	การค็นห
Condition 5B	ลูกช้าง	ลูกช้าง	ลูกช๊าง	ลูกช็าง

Examining Gamification in a Critical Design Themed Course: A Learning Objective Perspective

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Abstract: Educational gamification is no longer a novelty to researchers, as it has been positively approved of beneficial impacts on learning performance. However, a solid theoretical foundation of pedagogical gamification has not been fully constructed yet. This study proposes a gamification-dimensional teaching model from the perspective of learning objectives and applies it to a critical design themed course. Subsequent to analyzing the connotation of critical design and gamification, learning objectives, and appropriate game components, mechanics and dynamics have been determined. In addition to the commonly used game components such as PBL and achievement, avatar, content unlocking, chance, resource acquisition and narrative that are less involved in research are considered for this gamification design. Based on the proposed gamification strategies, offline teaching aids and an online application have been designed. Results indicate that this gamification design can effectively improve students' learning performance and their learning emotions including learning motivation and engagement.

Keywords: gamification; learning objectives; critical design; art education; teaching aid

1 Introduction

Gamification has already become a ubiquitous intervention, with its integration into various non-game contexts being positively affirmed by the market and users (Ming et al., 2017; Huotari & Hamari, 2017; Deterding, et al., 2011). Specifically, in the field of educational gamification, abundant research has proved that gamification in the form of either online or offline implementation generates significant benefit of improving educational outcomes and learning emotions, such as learning performance, engagement, and motivation (Kim et al., 2018; Dias, 2017; Crocco, et al., 2016; Tobias, Fletcher & Wind, 2014). This is found especially effective to the Generation Z, also known as digital natives, as the young generation has been highly exposed to games and technologies on a daily basis.

However, there remains controversial issues that need to be addressed in the field of educational gamification. One of the main problems rests in the lack of systematic theoretical models that enable to clarify the learning objectives, teaching strategies, evaluation, and their mappings onto the gamification design (Seaborn & Fels, 2015). So far, most education gamification research utilizes gamification design methods, rather than pedagogical models, to fulfil its educational aims, which triggers a consequence that the gamification process is arbitrarily designed with the most common game elements, such as PBL (points, badges, levels), rather than selecting the most appropriate game elements and mechanics based on the essence and goals of the course. Therefore, more educational approaches should be involved to clarify the characteristics and learning objectives of the course before the gamified design process. Moreover, in terms of selecting game elements and mechanisms, game elements such as chance, narrative, and role-playing that are relatively more complex should be examined in

gamification research so as to prevent it falling into a cliché that may greatly weaken the engagement and curiosity that gamification intended to bring (Raftopoulos, 2014). Hence, gamification mapped educational models and a wider application of the game elements are urgent to be proposed and adopted in educational gamification research.

Our study proposes a model consisting of learning objectives and gamification elements based on Bloom's revised taxonomy of learning objectives in cognitive domain (Anderson and Krathwohl, 2001) and Werbach's gamification hierarchy (Werbach & Hunter, 2012). Bloom's revised taxonomy of learning objectives in cognitive domain has been wildly adopted as a fundamental tool to educators, curriculum coordinates, and assessment specialists, as it provides them with clarification of the curriculum design as well as the instruction of teaching activities, and assessment. Since educational gamification mainly serves as an objective-orientated function, it would be effective to construct a gamification design model built upon Bloom's theory. To evaluate the model, we applied it to the gamification design of a 10-day critical design themed course. This course is based on the book of *Critical Design in Context*, which provides thorough explanation, discussion, analysis and evaluation of famous critical designers, groups, magazines and exhibitions originated from Italy, the United Kingdom, Sweden, and Germany (Malpass, 2017).

Through the combination of theory and application, this study 1) proposes a gamification teaching model based on Bloom's revised taxonomy of learning objectives and Werbach's gamification hierarchy. The model adds the gamification dimension to the "knowledge - cognitive process" structured model of Bloom's, and arranges 9 game components, mechanics and dynamics according to the learning objectives, which serves as not only theoretical foundation but also a design toolkit of the educational gamification; 2) analyzes the essence of the target curriculum, a critical design themed

course, and its connection to gamification design to maximize the impact of gamification on teaching effects, thus stimulating students' understanding and their application of critical design; 3) Selects less commonly used game components, mechanics and dynamics from the proposed model, such as avatar, content unlocking, resource acquisition, chance, and narrative to facilitate the gamification design of the target course; 4) A set of physical teaching aids and an online application are designed so as to evaluates the validity of gamification through the psychological and behavioral aspects, which involves the learning emotions and learning performance.

2 Theoretical background

2.1 Bloom's revised taxonomy of learning objectives and gamification design

Bloom's revised taxonomy of learning objectives in the cognitive domain suggested that a learning objective consisted of a verb and an object, with the former one referring an action in the cognitive process and the latter one describing the knowledge that students were expected to acquire (Anderson and Krathwohl, 2001). The cognitive process dimension included the actions of remembering, understanding, applying, analyzing, evaluating, and creating while the knowledge dimension was divided into factual, conceptual, procedural, and metacognitive levels. The definition of each dimension was presented by the authors. In the cognitive process, the dimension of remembering was defined as "retrieving relevant knowledge from long-term memory", such as recognizing and recalling. The dimension of understanding meant the "constructing meanings from instructional messages", including interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining. The dimension of applying aimed to "carry out or use a procedure in a given situation", such as executing and implementing. The dimension of analyzing referred to "break material into its

constituent parts and determine how the parts relate to one another and to an overall structure or purpose", including differentiating, organizing, and attributing. The dimension of evaluating required the "judgments based on criteria", such as checking and critiquing. The dimension of creating was defined as "put elements together to form a coherent or functional whole", including generating, planning and producing (Anderson and Krathwohl, 2001). Likewise, in the knowledge dimension, the factual knowledge referred to "the basic elements student must know to be acquainted with a discipline or solve problems in it", such as terminology and specific details. The conceptual knowledge meant "the interrelationships among the basic elements with a larger structure that enable them to function together", including classification, principles, and theories. The procedural knowledge was defined as "how to do something methods of inquiry, and criteria for using skills algorithms, techniques and methods". The metacognitive knowledge presented "the knowledge of cognition in general as well as awareness and knowledge of one's own cognition, i.e. strategic knowledge, contextual and conditional knowledge, and self-knowledge (Anderson and Krathwohl, 2001).

Once a learning objective is determined in the grid, the corresponding teaching activity and assessment can be consequently designed and filled into matching places. It is unnecessary to be a one-to-one correspondence between objectives, activities, and evaluations. For example, two learning objectives can be completed through one teaching activity and evaluated by one assessment, shown as in Figure 1.

Cognitive Process / Knowledge						
		Eg. Objective 1 Activity 1 Assessment 1				
						Eg. Objective 3 Activity 2 Assessment 2
				Eg. Objective 2 Activity 1 Assessment 1		

Figure 1. Bloom's revised taxonomy of learning objectives and examples

Gamification also follows the similar process, which consists of objectives, rules, feedback, and free wills (McGonigal, 2011). In educational gamification, the game objectives are usually equal to teaching objectives, and the game rules and feedback can be done through teaching activities and assessment. It should not be neglected that students are supposed to participate in the gamification process voluntarily, as the mandatory fun caused by poorly design often generates a negative impact on their psychological and behavior outcomes. Therefore, the core content of educational gamification lies in the fact of determining the effective game rules and feedback mechanism by selecting appropriate game elements, and finally achieving the teaching purposes. Werbach and Hunter (2012) proposed a gamification design hierarchy that included game components, mechanics and dynamics, as shown in Figure 2. Game components were defined as specific exemplification of game mechanic and dynamics, such as PBL, leaderboard and achievement. Game mechanics referred to processes that drove the action forward and incentivized users engagingly, which includes challenges, feedback, and reward, etc. Game dynamics, i.e. progression and emotion, offered the bigger picture or structure of the gamified system(Werbach & Hunter, 2012). Among them, avatar, content unlocking, collection, resource acquisition, chance, narrative have

seldom been applied in gamification research while others have been studied to certain extent.

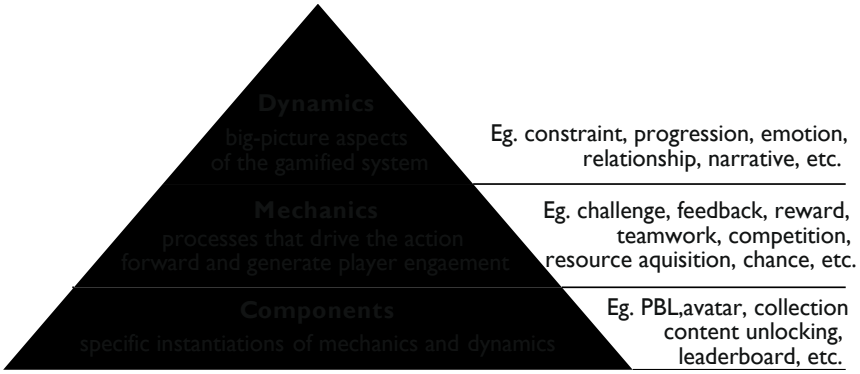


Figure 2. Werbach's hierarchy of gamification

Therefore, after combining the gamification design hierarchy with Bloom's revised taxonomy, we selected 9 less used elements from Werbach's hierarchy of gamification and proposed a gamification teaching model to enhance the gamification learning experience and learning outcomes of students in an innovative and comprehensive manner, shown as in Figure 3.

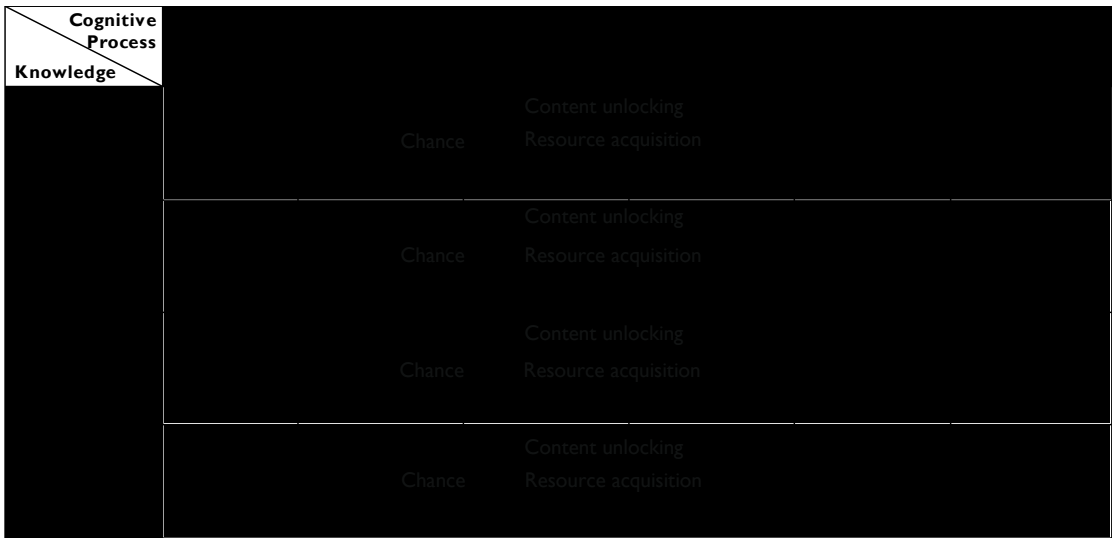


Figure 3. Proposed gamification teaching model

* yellow=game components, green=game mechanics, purple=game dynamics

(1) Game components

Avatar serves as a suitable component for the learning of factual and conceptual knowledge that always involves with novel terminology and principles, for avatar's ability of information visualization can add visual sensory to the learning experience through either figurative or abstract graphics to improve the learning outcomes. It is undoubtful that visual signals have been proved to be the most effective information carrier in the cognitive process for human beings. Moreover, scholars have found that avatar is frequently used to simulate impractical procedural operations within the virtual world, so as to reduce the investment of time, space and capital in the process of procedural knowledge learning (Kohler, Matzler, & Füller, 2009). In addition, avatar users would conform the behavioral expectation with the avatar characteristics when they perceived the avatars self-presented (Yee, Bailenson & Ducheneaut, 2009). Thereby, it is assumed that avatar can not only enhance the perception of first encountered factual and conceptual knowledge, but also be helpful to influence the perception of procedural and metacognitive knowledge.

Content unlocking could be beneficial to learning activities due to the Foot-in-the-door (FITD) Technique that it utilizes. FITD Technique is posited by psychologists as that people tend to agree with a large request by having them agree to a modest request first (Freedman and Fraser,1966). Requesters may gradually shape the attitude and behavior of requestees with such successive approximation to satisfy their own goals or interests. Content unlocking happens to take advantage of such trivial-to-complex or low-to-high threshold design for users to complete larger tasks. It is therefore assumed that content unlocking would facilitate the learning process involving variation in difficulty, and dimensions, such as from factual, to conceptual, and to procedural knowledge due to its progressive property.

Collection as a game component works for learning activities because of the Zeigarnik Effect that occurs. Psychologists contend that individuals incline to remember tasks that have already started but not completed yet compared to those have been finished, coined as Zeigarnik Effect, for the unfinished work can produce continuous task-specific tension that makes it more easily accessible and remembered(Zeigarnik, 1927; Lewin, 1935). People who are in favor of collecting would always cherish such suspending feelings and be motivated to accomplish their collection as comprehensively as possible, which would be helpful to the acquisition of knowledge in any dimensions. When such behavior is patterned, collecting would shift its focus on a process of achieving a sense of accomplishment by linking certain specific memories and experiences with specific objects. Many collectors have a strong commitment and pursuit of the integrity of the collection, which acts as a catalyst for learning how to acquire, to formulate strategies, and to satisfy the psychological needs on a metacognitive level.

(2) Game mechanics

Chance has been considered as a high user viscosity game mechanic because it exactly favors the human nature of gambling. The probability and algorithm behind the chance can always motivate players' desires for luck, which can also subtly stimulate students' acquisition of unknown knowledge in disguise. This can be explained by the principle of Skinner box, which suggested that random rewards could promote a continuous occurrence of the desired behaviors of users compared to regular rewards or punishments (Skinner, 1938). Such approach is often adopted to shape the learning behaviors of students so as to achieve the educational goals (O'Leary & Becker, 1967), which can be applied to every knowledge dimension.

Resource acquisition, as a suitable game mechanic for driving the components of content unlocking and collection, is able to provide players with “raw materials” of the next task by making effort on gradually completing the preceding tasks. At the same time, it may also improve learning efficiency of metacognitive knowledge through goal-setting with the joy and sense of accomplishment.

(3) Game dynamics

Constraint can effectively motivate players to challenge themselves with the various steerable items in the situated gaming environment. It is in favor of promoting the learning of factual and conceptual knowledge (Pivec, 2007), by limiting the time, space, skills, cooperation and other conditions to increase the difficulty of learning skills.

Progression is a fundamental reason for humans to generate motivation of learning. It serves as a good indicator of what players have achieved in an unknown field. Researchers have examined that progression would be suitable for obtaining procedural skills based on feedback systems that measure the competency of learners (Kapp, 2013; Yunyongying, 2014). At the same time, it also contributes to other three knowledge dimensions, as it shares the similarity of instructional scaffolding, both of which provide learners with support, instruction, guidance, abilities of independent problem solving to accomplish the learning of mastery (Day-Black, 2015).

Relationship is a necessary option in gamification design because relatedness is a significant basic psychological need that generates intrinsic motivation (Ryan & Deci, 2000). It can represent many complex relationships between the game's progress and the player's social interaction, which often improves the integrity and playability of the gamification design system.

Narrative uses plot design with a sense of empathy to subtly transform learning into the process of obtaining knowledge and skills under a particular context. An exquisite narrative design can greatly serve the acquisition of procedural and metacognitive knowledge because specific goals, situations, and scenarios can provide players with the chance to form the ability of problem solving, decision making, and strategic thinking ((Pivec, 2007; Rowe et al., 2010).

Gamification and critical design

Since educational gamification aims to achieve the established teaching objectives, exploring the connection between the characteristics of the curriculum itself and gamification is a determinant prerequisite for retaining high-quality learning results. This study takes a critical design themed course as the application object, and the connotation of gamification and critical design is discussed in depth. First, gamification design and critical design all rest within the scope of design, which mainly discuss the various interaction between humans, environment, and objects. More precisely, design can be divided into mainstream design and critical design (Malpass, 2017), while gamification design is part of the mainstream design, as shown in Figure 4. As a category of mainstream design, the ultimate goal of gamification design is problem solving by the means of user-friendly game mechanics to improve users' psychological and behavioral outcomes. Oppositely, critical design aims to discover problems via user-unfriendly design methods to trigger the reflection and discussion from users. For example, as shown in Figure 5(a), Dunne and Raby designed their ironic artwork "Faraday chair", which became a kind of psychological suggestion, showing that while human beings extend their bodies infinitely in function with the ubiquitous electromagnetic pollution, their inner world gradually shrinks and closes(Dunne & Raby,

2014). The "Faraday chair", like a uterus, psychologically creates a sad space, as if telling people that it is you who have turned this into your last refuge.

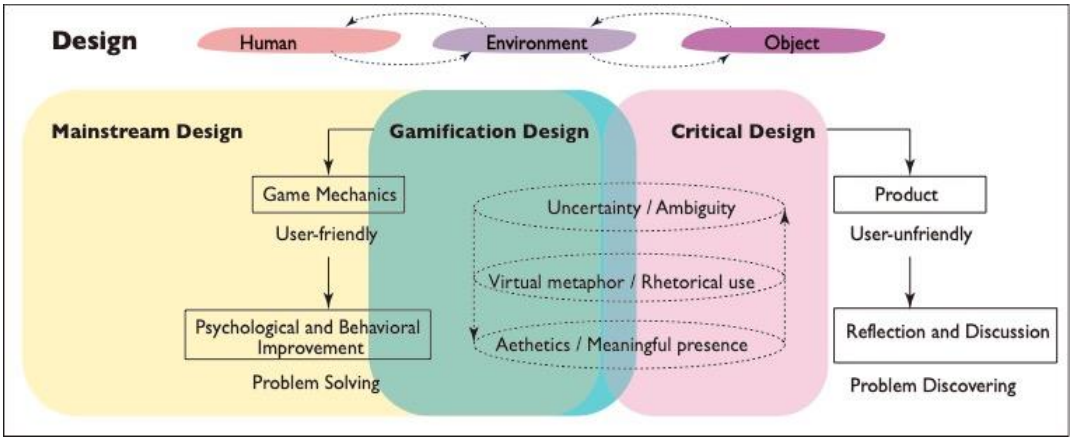


Figure 4. Relationships between gamification and critical design

(a) Faraday Chair by Dunne and Raby (b) Traces of an Imaginary Affair by Björn Franke

Figure 5. Examples of critical design

Even though it is of great difference between gamification and critical design in terms of the carrier, user experience, purposes, and results, there are still surprising similarities in their design connotation. First, the core design strategy of critical design is "ambiguity", which aims to have a defamiliarizing and estranging effects to dissociate the users from their normal modes of use (Baudrillard, 1981). Critical design allows viewers to think and reflect on individuals, things, and the environment from a new perspective by transforming the background used in product design, the definition of the product itself, and the relationship between the product and the user. As shown in

Figure 5(b), Björn Franke designed a self-harm toolkit for users to feel self-worth (Franke, 2009). The design challenges viewers stereotypical beliefs in that self-harm is wrong while faked harming can instill value and worth. Correspondingly, the ambiguity of gamification lies in the uncertainty of the results, which strives players to pursuit unknown game outcomes by following established game rules. This enables the gaming process to be of great exploratory, curiosity, frustration, and challenges, so as to reinforce players' enters of the state of flow (Csikszentmihalyi, 1990). The ambiguity of critical design and the gamified uncertainty exactly take advantages of humans' the infinite pursuit of possibility so as to intrigue viewers with pleasures, satisfaction, doubts, and reflection.

Secondly, the rhetorical attribute of critical design and the virtual metaphor produced by gamification share similarities to great extent. Critical design has always been designed within a context or scenario in order to give meanings to the object, which implies a certain way of rhetorical interaction between viewers and the object to enhance the validity of the scenario. It allows critical design to freely manipulate objects and reflection of viewers via the rhetorical meanings. Similar, gamification realizes players' psychological and behavioral values by fictitious scores, badges, levels, stories, fantasy, emotions, etc., as a virtual metaphor to improve players' tedious, repeated, and burdensome activities. It is, therefore, an optimization of the real life that critical design and gamification propose to challenge individuals of their accustomed thoughts and the environment.

Finally, critical design and gamification all devote themselves to making things meaningful by the means of aesthetic. Critical design establishes a relationship between objects and humans via aesthetics, de-familiarization, and estrangement discover, so as to deepen the understanding of dynamic rules of the reality. Gamification applies

aesthetics to facilitate the problem-solving process by creating hedonic experience and meaningful presence.

Since critical design and gamification share overlaps in design strategy, design methods, and design nature, the essence of ambiguity, rhetorical use, and meaningful presence should be of great consideration in terms of choosing appropriate game elements during the process of gamifying a critical design themed course, so as to maximize the optimization of gamification for the course requirements.

3 Study Design

3.1 Critical design themed course and participants

The application of this research is a 10-day critical design themed course, which includes explaining, analyzing, discussing and evaluating the art practices of famous critical designers, groups, magazines and exhibitions from four representative countries such as Italy and UK. Students are required to remember and understand the related concepts and design process of famous products, to master the critical design methods, and to create their own design practice.

Participants of this study are 56 industrial design majored senior undergraduate students from a university in Beijing. Before the course starts, the participants are randomly distributed to the experimental and the control groups. The participants in the experimental group will accept the gamification intervention during the learning process, whereas the control students will not. The two groups of participants will attend the same assessment at the end of the course, which includes a closed-book exam, a group presentation, and a critical design themed video shooting.

3.2 Gamification design of the critical design themed course

Based on the proposed gamification teaching model and the analysis of the characteristics of the target course, this study assumes that applying this theory to the critical design themed course will significantly improve participants' learning outcomes and learning emotions. The research framework of the study design is shown as in Figure 6.

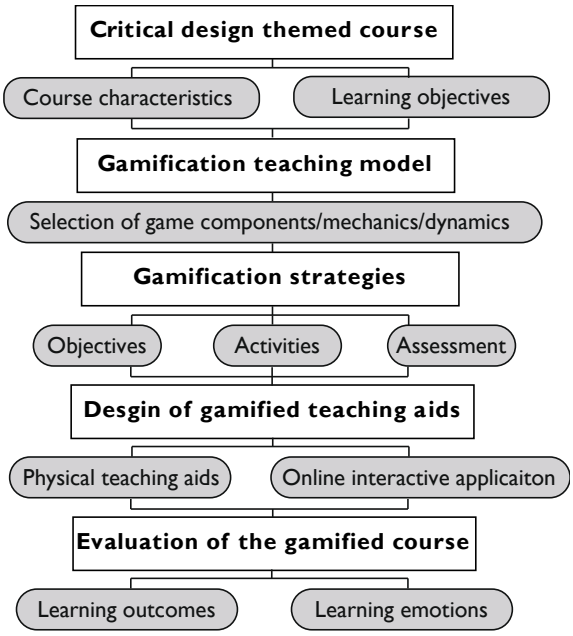


Figure 6. Framework of the design study

3.2.1 Learning objectives and selection of game elements

The learning objectives and the selection of game components, mechanics, and dynamics (besides basic gamification elements such as PBL and leaderboard, etc.) are listed as following and shown as in Figure 7.

Objective 1: Memorize the names of at least one prestigious critical designer in each of the four countries, his or her iconic artwork, the group that he/she belongs to, the exhibition that his/her work was presented, or the magazine that he/she used to edit.

Objective 2: Understand the similarities and difference between critical design and mainstream design, and the variation of critical design between different countries.

Objective 3: Analyze the social context of 2-3 reputable critical design works, their designers' biographies, the adopted design methods and processes, and the design intents and impacts.

Objective 4: Evaluate the critical design works and the presentation skills based on the peers' speech presentation.

Objective 5: Create a "What if..." themed video shooting by using the critical design methods.

In order to meet the above five teaching objectives and refer to our proposed gamification teaching model, suitable game components, mechanisms, and dynamics are selected, shown as below.

To achieve Objective 1 and 2, avatar is chosen as a game component because of its ability of visualizing unfamiliar information that are difficult to remember, so as to improve the memory efficiency of participants. Besides the visualized graphics, content unlocking is selected, for it may facilitate the clarification of serial learning goals and the production of curiosity and mystery about the unknown knowledge. As a game mechanic assorted with content unlocking, resource acquisition is consequently included. Using chance as another game mechanic aims to provide students with a gambling or uncertain experience so as to obtain a more comprehensive understanding of knowledge. With these components and mechanics included, constraint and relational perception is produced, just as the game dynamics intend to bring.

For Objective 3 and 4, during the analysis and evaluation of factual and conceptual knowledge, students continue to acquire new resources based on the results obtained from content unlocking in the process of Objective 1 and 2. When encountering procedural and metacognitive knowledge, students may experience the procedural progress, which lead to the join of progression as a dynamic.

In order to accomplish Objective 5, the results of the resource acquisition caused by the preceding content unlocking can still be the basis in this phase. Since Objective 5 is related to creation, the adding of chance as a mechanic promotes innovation produced by the uncertainty and constraint. In the stage of creating procedural and metacognitive knowledge, narrative is included as a dynamic because the empathy caused by a storytelling can be more reflective to the viewers.

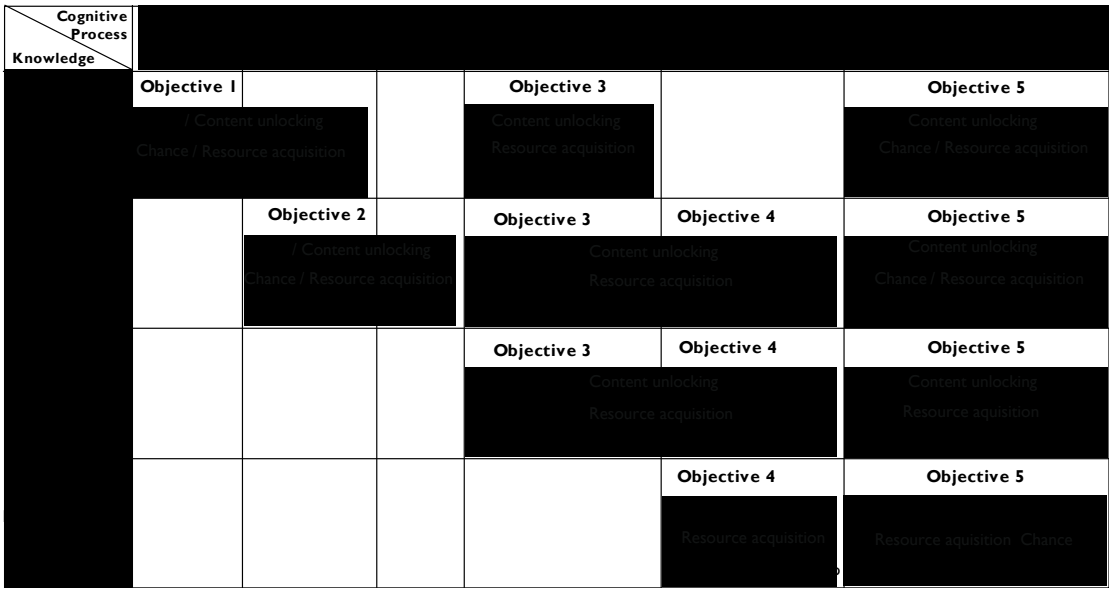


Figure 7. Learning objectives and selection of game elements

3.2.2 Gamification strategies

Based on the selected game components, mechanisms, and dynamics, combined with the course content, gamification strategies are generated, which include the objectives, learning activities, and assessment, shown as in Figure 8.

In order to achieve Objective 1 and 2, the tutor delivers the instruction of prestigious critical designers, design works, design groups, exhibitions, magazines, design concepts and style differences, referred as critical design units, by using the pictures, videos, and other conventional multimedia teaching methods. When each design unit is explained, the tutor will present a corresponding paper card that

represents the design unit. Students can obtain these paper cards by answering the questions and asking critical questions during the classroom interaction. These cards can be scanned by the designed smart-phone based application and the corresponding avatars and points that match the cards will be gained. The points can be used to unlock the mainline tasks, bonus tasks, and exchange for game props that include limited avatars, opportunities of replacing existing resource, opportunities of acquiring additional resource, etc.

Cognitive Process / Knowledge						
	Objective 1 Activity 1 Assessment 1			Objective 3 Activity 2 Assessment 2		Objective 5 Activity 3 Assessment 3
		Objective 2 Activity 1 Assessment 1		Objective 3 Activity 2 Assessment 2	Objective 4 Activity 2 Assessment 2	Objective 5 Activity 3 Assessment 3
				Objective 3 Activity 2 Assessment 2	Objective 4 Activity 2 Assessment 2	Objective 5 Activity 3 Assessment 3
					Objective 4 Activity 2 Assessment 2	Objective 5 Activity 3 Assessment 3

Figure 8. Learning objectives, activities, and assessment of the critical design course

(1) Activity 1 and Assessment 1

Assessment 1 includes the student's performance in the app and a closed-book exam. The performance in the app requires each student to obtain at least one avatar and corresponding points in order to unlock the first mission of the mainline tasks, thus being qualified to complete the course. The first mission of the mainline task is a one-hour closed-book exam, which is based on the content about the design unit that the tutor has introduced. The questions include multiple-choice questions, blank questions, and discussion questions. Only students who pass the exam can start the Activity 2. The bonus task is optional, which implies that the student is able to earn more points by answering course related questions at spare time.

Activity 1 enables students to convert the factual and conceptual knowledge taught by the tutor into perceivable and memorable concepts, and to seize more possibility of getting new resource by unlocking content through better learning performance.

(2) Activity 2 and Assessment 2

Activity 2 is a group assignment, which requires students to analyze and evaluate 2-3 design units from the perspective of social background, design works, the biographies of designers, the adopted design methods and processes, and the design intents and impacts. The group should perform a 10-minute presentation to complete Objective 3 and 4. The group's choice of design unit entirely depends on the avatars accumulated in Activity 1. One can determine the design unit either from the acquired avatars or redeem extra avatars by using the points. Team members can share the acquired avatars. The more avatars a group possesses, the more topic novelty of its presentation may bring.

The criteria of Assessment 2 include the topic novelty, analysis reasonability, evaluation objectivity, presentation skills, and teamwork ability. Each group’s presentation will not be scored by the course tutor but another two design majored tutors and students of other groups in a ratio of 6:4. These two tutors are unaware of this study but acquainted with the curricular content and evaluation criteria. The purpose of inviting other tutors and peer review aims to eliminate the influence of the course tutor on the assessment, so as to obtain the objective result as much as possible. The score of the presentation will be accumulated to the student's existing points for obtaining new resource in the next activity. Only the students with presentation scores that exceed the pass line are able to unlock the next mainline task (Activity 3).

(3) Activity 3 and Assessment 3

In order to achieve Objective 5, Activity 3 requires students to present a "What if..." themed video shooting with the adoption of at least one of the three critical design methods to depict a future design. The subject of "What if" is a term that present unlimited hypothetical meanings, which is in line with the essence of critical design, provoking open-answered discussion and reflection from the viewers. Students can determine the topic by completing the “What if” sentence and choose the design method of “context transfer”, “cut up”, and “hybrids” that the tutor has discussed in the class. However, the choice of design method is not on freewill by the group, but the draw of a random avatar redeemed by points. With sufficient points, students are able to win extra chances of draws. The acquired method avatars can be replaced or accumulated, implying that a group can adopt at most three types of design methods for the themed critical design.

The criteria for Assessment 3 consist of the topic novelty of the proposed design, the appropriateness of design methods, the logic and coherence of the script and plots, the aesthetics of the visual sensation, and the teamwork ability. This activity will be scored by the same two tutors as in Assessment 2 and students of other groups in a ratio of 6:4. Only the students who unlock and pass all the three activities that can complete the course. The final grade of this course is composed of the closed-book exam, group presentation, and the video shooting in a ratio of 2:3:5.

3.2.3 Design of gamified teaching aids

In order to cope with the proposed gamification strategies, the teaching aids and application are designed, including a set of paper cards and a smartphone-based application. Each card corresponds to a design unit that the tutor mentioned in the class, and the visual elements of the cards include the Chinese and English names for the

design unit, the core image, and the geometric shapes that imply the representative colors of the country, shown as Figure 9.

Figure 9. Designs of paper cards for critical design units

After acquiring the card, students can start interacting with the app. The main interaction process includes unlocking the mainline and the bonus activities, collecting avatars and points, redeeming reward items, carrying out critical design work, and viewing the results of peers and their own, shown in Figure 10.

3.2.4 Evaluation of the gamified course

Students' learning performance is assessed by the scores of the closed-book exam, the group presentation, and the critical design themed video shooting. The learning emotions are measured by a survey in aspects of learning motivation and engagement in Likert scales. The collected data were processed by IBM SPSS.

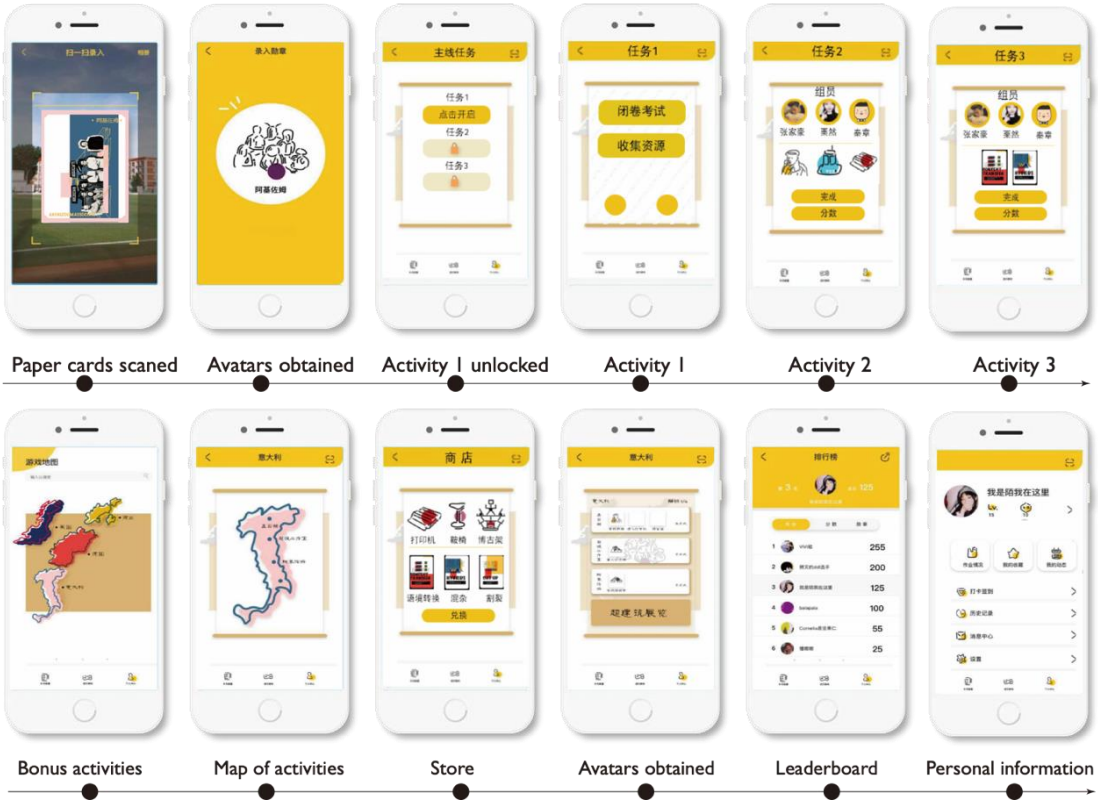


Figure 10. Main UIs of the app

For learning performance, after the data of three assessments and final score from the control and the experimental groups being tested as a normal distribution, a set of independent-samples t-tests were performed, as shown in Table 1. The results indicate that the learning performance in all assessments of the experimental group, except for Assessment 2, was significantly improved compared with that of the control group(t=-2.195, p=0.032; t=-2.615, p=0.012; t=-2.249, p=0.029), which implies that the implemented gamification generates a positive impact on the overall learning performance but not in the part of group presentation. Specifically, with higher scores in the closed-book exam and the video shooting assignment from the experimental group, we can conclude that our implemented gamification is beneficial to the fulfillment of the learning objective 1, 2, and 5, namely better remembering the factual knowledge, understanding the conceptual knowledge, and creating the factual, conceptual, procedural, and metacognitive knowledge that related to the requirement of this critical

design themed course. Nevertheless, the learning objective 3 and 4 were not satisfied by the implementation of gamification. Hence, the sub-scores according to the criteria of Assessment 2 from the control and experimental groups were compared and analyzed with independent-samples t-tests, shown as in Table 2. It is found that the sub-scores regarding of topic novelty and teamwork ability were significantly increased in the experimental group (t=-2.012,p=0.049; t=-2.029,p=0.047) while the counterparts of analysis reasonability, evaluation objectivity, and presentation skills show no major changes. In Activity 2, the topic novelty of group presentation heavily depends on the resource acquired in Activity 1, and the teamwork ability mainly relies on the academic collaboration and the social achievements within the gamification application, which may both have little to do with the ability of analyzing and evaluating. The core training of analyzing and evaluating was presented by the tutor in class rather than being reinforced with gamification. It is therefore considered that the implemented gamification benefits the accumulation of factual and conceptual knowledge as well as the increase of team social ability even though it failed to elevate the overall analytical and evaluation skills of students.

For learning emotions, the normally distributed data of learning engagement and motivation from the control and experimental groups were also performed with independent-samples t-tests, shown as in Table 3. The results indicate that significant improvement in both learning engagement and motivation were found in experimental group compared with those of the control group (t=-3.683, p=0.001; t=-2.899, p=0.005). Moreover, the relationships between the final score and learning motivation and engagement were analyzed, shown as in Table 4. It is shown that the final score is highly correlated to the learning engagement and motivation. Linear regression models were established as shown in Figure 11. It is therefore concluded that the implemented

gamification can significantly increase the learning engagement and motivation of students. Meanwhile, this study also proves that learning engagement and motivation is highly correlated to learning performance, which is consistent with many extant educational gamification studies (Sailer & Hommer, 2019).

Table 1 *t*-Test for course assessments

Assessment	Mean		*t*	*p*
	CG	EG		
Assessment1	79.32	83.46	-2.195	0.032
Assessment2	78.29	79.43	-4.860	0.629
Assessment3	77.43	82.86	-2.615	0.012
Final Score	78.06	81.95	-2.249	0.029

Table 2 *t*-Test for sub-scores of Assessment 2

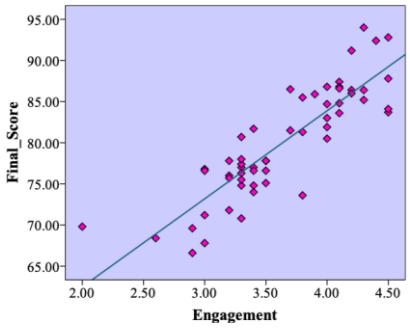
Criteria for Assessment 2	Mean		*t*	*p*
	CG	EG		
Topic Novelty	13.54	15.14	-2.012	0.049
Analysis Reasonability	15.57	15.43	0.285	0.777
Evaluation Objectivity	16.04	15.71	0.756	0.453
Presentation Skills	16.86	16.14	1.599	0.116
Teamwork Ability	16.29	17.00	-2.029	0.047

Table 3 *t*-Test for learning emotions

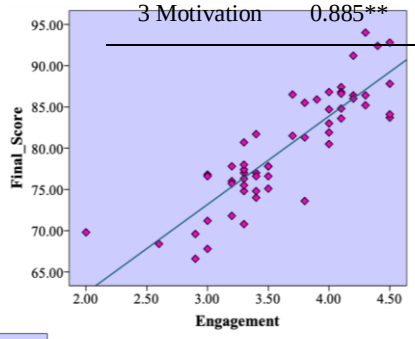
Learning Emotions	Mean		*t*	*p*
	CG	EG		
Engagement	3.40	3.88	-3.683	0.001
Motivation	3.67	4.01	-2.899	0.005

Table 4 Correlations between learning emotions and final score (N=56)

Variables	1	2	3
1 Final Score	1		
2 Engagement	0.867**	1	
3 Motivation	0.885**	0.885**	1



(a) Linear regression model of final score and engagement



(b) Linear regression model of final score and motivation

Figure 11 Linear regression models of final score and learning emotions

4 Conclusion

This study proposes a gamification-dimensional teaching model and applies it to a critical design themed course. In the process of gamifying the target course, the analysis of the connotation of critical design and gamification, learning objectives, and appropriate game components, mechanics and dynamics have been conducted and determined. In addition to the commonly used game components such as PBL and achievement, avatar, content unlocking, chance, resource acquisition and narrative that are less involved in research are considered for this gamification design. Based on the proposed gamification strategies, offline teaching aids and an online application have been designed. The results show that the implemented gamification can effectively improve students' overall learning performance and learning emotions including engagement and motivation.

In this proposed gamification teaching model, the game components, mechanics, and dynamics and their corresponding positions in bloom's revised taxonomy can be discussed and modified in depth by the means of involving more psychological, behavioral, and pedagogical theories, so as to improve the validity of the model. Moreover, the mechanism of how gamification stimulating students' learning of factual and, conceptual, procedural, and metacognitive knowledge related to critical and creative design should be further studied, as gamification could be a novel and significant approach to the cultivation of creative and critical thinking in the field of design and art education. Further, the implemented gamification in this study has not positively improved the analyzing and evaluating ability of students, which implies that modification for a better gamification strategy design should be carried out. Lastly, more research needs to be continued in regarding of exploring all game elements in this

model within the context of diverse disciplines in order to solid the theory and evaluate its effectiveness.

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A Comfort Evaluation of Aircraft Passenger Based on Muscle Activation and Perceived Discomfort during Long Flights

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AbstractB： Introduction: Air travel is increasing around the globe, so it is crucial to improve passenger comfort on flights. The purpose of this study is to investigate the comfort of aircraft passengers during long flights and to determine the effects of the seatback angle and the seat pitch on passenger comfort. Methods: All participants sat on an economy class aircraft seat for 2 h with different levels of seatback angle and seat pitch. Subjective discomfort scores and RMS (root mean square) and MPF (mean power frequency) values were used to evaluate muscle fatigue, and all data were calculated for every 15 min interval. Results: A slight increase in the RMS and a decrease in the MPF, along with a remarkable increase in the PLD (perceived levels of discomfort), were found over 2h. The increased trend of the RMS and the decreased trend of the MPF occurred around 30 min. However, a 120 ° seatback angle and a 34" seat pitch resulted in lower PLD values for the lower back and hip areas than smaller ones (significant difference). These two factors seem to have only a few effects on muscle fatigue according to the MPF. Discussion: This study suggests that sitting in economy class seats during a long-haul flight could lead to muscle fatigue and pronounced discomfort in the upper body regions. The larger parameters of seatback angle and seat pitch may significantly contribute to the easing of subjective discomfort.

Keywords: Ergonomics; muscle fatigue; aircraft seat; RMS; MPF.

Introduction

In 2013, according to a report by the Air Transport Action Group (ATAG), over 3 billion passengers were carried by global airlines ("ATAG," 2015). The sales volume of air travel will double in the next fifteen years, showing 4.7% annual growth between 2013 and 2033 ("Global Market Forecast 2014-2033," 2012). Additionally, a previous study reported that at least 35% of passengers chose an airline based on a previous comfortable experience in an aircraft cabin (Brauer, 2006). In other words, the business of airlines will be affected by passengers' subjective feelings and experience, so airlines should focus on the development of a comfortable aircraft environment to attract more passengers. These aspects directly affect the passengers' experience and willing to travel.

Comfort and discomfort are defined as feelings or emotions that are subjective in nature (De Looze, Kuijt-Evers, & Van Dieën, 2003). Different methodologies are divided into subjective methods (e.g., Borg scale) and objective methods (e.g., pressure measurements, electromyography and posture analysis) to measure sitting comfort. On one hand, the PLD is an effective method to quantify perceived discomfort (Babski-Reeves, Stanfield, & Hughes, 2005). On the other hand, muscle activation is one of the common objective evaluations. For instance, previous researchers have investigated the comfort or discomfort factors and response using electromyography (EMG) activity (Hiemstra-van Mastrigt, Kamp, van Veen, Vink, & Bosch, 2015; Winkel & Bendix, 1986; Yang & Kang, 2016). Lee et al. (1988) demonstrated that increased muscle activation in the shoulders and back was significantly related to increased discomfort while performing a microscopic task on one seat. It has also been proven that prolonged sitting in a restricted posture is associated with negative health outcomes, such as lower back pain (Tissot, Messing, & Stock, 2009; Truszczyńska, Lewkowicz, Truszczyński,

Rąpała, & Wojtkowiak, 2012) and neck pains (Nejati, Lotfian, Moezy, & Nejati, 2015). In addition, in the amplitude domain, the root mean square (RMS) is considered to be more suitable to illustrate changes in the EMG signal caused by muscular fatigue (Luttmann, Jäger, & Laurig, 2000). However, the median frequency (MF) and the mean power frequency (MPF) are the most commonly used frequency domain features for EMG signal processing (Wang, Bartuzi, & Roman-Liu, 2013).

Seat pitch (legroom) is seen as a critical comfort criterion by passengers and a discomfort indicator by ergonomists (Richards & Jacobson, 1977), especially during long-haul air travel (Tan, Rauterberg, Chen, & Kher, 2012). The easiness of adopting a comfortable sitting posture is significantly influenced by the seat pitch (Kremser, Guenzkofer, Sedlmeier, Sabbah, & Bengler, 2012). The seatback angle is also one the crucial factors affecting sitting comfort (Jung, Han, Jung, & Choe, 1998). Andersson et al. report that it is beneficial to angle the seatback to the rear, but if the increased seatback angle is combined with reduced legroom, passengers will be forced to extend their knees (Andersson BJ, Ortengren R, Nachemson A, 1974).

Few studies, if any, have investigated the issue of (dis)comfort assessment based on the ergonomic exposures of aircraft passengers, although a considerable amount of studies have focused on physical environment factors, such as the thermal, vibration, noise, pressure and air quality, of the over-cabin environment (Baumann & Trimmel, 2013; Ciloglu, Alziadeh, Mohany, & Kishawy, 2015; Kanick, 2005; Z. Li, Guan, Xudong Yang, & Lin, 2014; Yin et al., 2016) and the seat comfort of office chairs, automotive seats and pilots' seats (Kolich, 2014; Sako et al., 2014; Truszczyńska et al., 2012).

Consequently, the present study investigates the influences of the seatback angle and the seat pitch on the upper body muscles (neck, shoulder and lower back) of aircraft passengers and the subjective discomfort in the relevant body regions.

Methods

Fifteen healthy participants were recruited for this the study, including seven males (mean±SD height, 174.6±3.3 cm; sitting height, 93.1±2.6 cm; mass, 76.7±9.8 kg; age, 25.0±2.9 yrs), and eight females (mean±SD height, 167.1±3.8 cm; sitting height, 88.4±3.1 cm; mass, 53.6±3.5 kg; age, 24.1±1.1 yrs). All participants were free from any chronic or acute upper body pain in the previous 6 months. All subjects provided informed written consent and this study was approved by the university's institutional review board.

The experiment was conducted in a laboratory environment with an adjustable aircraft seat. Subjects were asked to sit on the seat in a preferred posture and performed a 2 h experimental reading task while sitting in the seat for four trials over four days. These four trials were performed in a random order, separated by at least 48 h to minimize fatigue effects.

The experiment had a nested factorial design. Two independent factors were manipulated and three classes of dependent measures were recorded. Independent variables included the seatback angle (2 levels, 90° and 120°) and the seat pitch (2 levels, 28" and 32"). The seatback angles (measured from the seatback to the horizontal) were described as 90° and 120° backrest inclinations. The seat pitch was defined as the distance from a point on the seat in one row to the same point on a seat in the next row (Kremser et al., 2012). The dependent variables were the EMG amplitude and the discomfort experienced during sitting tasks.

Participants completed a demographic questionnaire prior to data collection. The skin surfaces of the three muscles were abraded and cleaned with alcohol, and surface electrodes were attached. Following a 15-min stabilization period, impedance was measured to ensure impedance below 10 kΩ. Prior to the commencement of the tasks, participants were briefed about the tasks.

Maximum voluntary contractions (MVCs) were performed and recorded to normalize the EMG signals. Resting EMG signals were sampled at 5 Hz for 5 s while the participants were sitting straight in the aircraft seat with both feet flat on the floor. A 5-s ramp-up and ramp-down procedure was used to collect the MVCs. A cervical erector spinae (CES) contraction was captured by extending the neck and head against the resistant arm of a Kin/Com dynamometer (Chatanooga Group, Inc., Hixson, TN) , contacting at the subject's occipital bone (Schüldt, 1988). An upper trapezius (UT) contraction was obtained by holding a 0.5 kg dumbbell in each hand, with the arm abducted at 90 ° in the frontal plane and parallel to the floor (Yoo, Jung, Jeon, & Lee, 2010). A lumbar multifidus (LM) contraction was captured by holding the hands on the neck and lifting the head, with the shoulders and elbows just off the examination table and the subject positioned prone, legs straight, and strapped in with a belt (O'Sullivan et al., 2006). A minimum of two trials lasting 5 s each with a 30s rest period between exertions were performed. The EMG value was measured with AcqKnowledge 3.9.1 software.

Myoelectric activity was collected using MP150 Biopac Systems and AcqKnowledge Software (Biopac Systems Inc, Goleta, CA, USA) was used for EMG acquisition. Ag/AgCl pre-gelled bipolar disposable electrodes were attached. Raw EMG signals were recorded and differentially amplified at a sampling rate of 2000 Hz and band pass filtered (10–500 Hz for surface recordings). For activation measurement,

signals were smoothed (2000 sample/window) then rectified (400 sample/window) to calculate the amplitude at 5-s intervals. The electrodes were sited on the following muscles of the right side of body focused on shoulder and back: CES - 2 cm lateral from the C4 spinous (Caneiro et al., 2010; Strimpakos, Georgios, Eleni, Vasilios, & Jacqueline, 2005); UT - lateral to the half-way point of an imaginary line formed by the posterior aspect of the acromion and the spinous process of C7; LM - L5 level and aligned parallel to a line connecting the posterior superior iliac spine and the L1-2 interspinous space (De Foa, Forrest, & Biedermann, 1989). Raw EMG signals were amplified and computed as MPF and RMS values at times of 15, 30, 45, 60, 75, 90, 105, and 120 min.

PLD were assessed using a modified Borg's perceived level of exertion scale (Babski-Reeves et al., 2005). Participants were asked to verbally provide a rating of discomfort on the parts of neck (NEC.), left shoulder (LS), right shoulder (RS), left lower back (LLB), right lower back (RLB), left hip (LH) and right hip (RH) at the start of each test and every 15 min thereafter for the remainder of the experiment (9 times for each test).

Two-way repeated measures analyses of variance were conducted (for two levels of seatback angle and two levels of seat pitch) followed by Tukey's honestly significant difference post hoc analyses, where significant main effect differences were found. Significant interaction effects were further examined using a simple effect analysis. Line plots were portrayed to evaluate the trends of the RMS, MPF and PLD over time. All statistical analyses were completed using SPSS (IBM SPSS Statistics, Version 22) and all results were considered significant at an alpha level of 0.05. The RMS and MPF were calculated using a program developed by MATLAB (Mathworks Inc., Natick, MA, USA).

Results

Descriptive statistics for dependent variables and ANOVA results are presented in Table 1, which shows the main effects of the seat pitch and seatback angle and the seatback angle × seat pitch interaction effects on muscle activation and perceived discomfort. To clarify, the combinations of seatback angle/seat pitch were on behalf of different trials as follows: 90 °/30" (T1), 90 °/34" (T2), 120 °/30" (T3), and 120 °/34" (T4).

[TABLE I here]

The analysis of the seatback angle effects yielded a significant result for the CES ($p = 0.004$) and UT ($p = 0.000$) muscle activity only. However, the CES was significantly influenced by the factor of seat pitch ($p = 0.000$). No seatback angle × seat pitch interaction effects were found for the RMS data. No significant differences between each trial were found for RMS values of the three muscles (see Table 1).

Fig. 1 shows an increase trend of the RMS over time for all three muscular regions, especially for the UT, although the results revealed no statistically significant changes in the RMS over 2 h of sitting in the aircraft seat.

[Fig. 1 here]

The MPF values of the seatback angle × seat pitch interaction showed significant result for CES muscle activity only ($p = 0.001$). Further Tukey's multiple comparison tests of CES indicated that for T1 vs. T3, $p = 0.041$ and for T3 vs. T4, $p =$

0.048 (Table 1). No seat pitch, seatback angle effects were found for any trials.

No statistically significant changes in MPF over 120 min are found in Fig. 2.

Declined trends of MPF were seen over time for all three muscular regions. In general, for all three muscles, 30 min measurements were elevated in comparison with the MPF measurements at the time of 15 min.

[Fig. 2 here]

Table 1 reveals no significant difference in seatback angle, seat pitch, or seatback angle × seat pitch effects for the local body parts of the neck (NE.), the left shoulder (LS) and the right shoulder (RS) (Table 1).

The mean PLD of the right lower back (RLB) was significantly different ($p = 0.19$) and no differences were found between other body parts for the seatback angle. In general, fewer discomfort values were found for the angle level of 120 °.

It was shown that the mean PLD of the right lower back (RLB), the left hip (LH) and the right hip (RH) were significantly different ($p = 0.029, 0.029, 0.010$) between each seat pitch.

The mean PLD of the left lower back (LLB) and the right lower back (RLB) were significantly different ($p = 0.028, 0.007$) and no differences were found between other body parts for four different trials. Tukey's multiple comparison tests revealed that the PLD values of the LLB [T1 vs. T2 ($p = 0.029$), T1 vs. T3 ($p = 0.025$)]; RLB [T1 vs. T2 ($p = 0.003$), T1 vs. T3 ($p = 0.002$), T1 vs. T4 ($p = 0.008$)] for T1 were higher than those of the other trials.

As shown in Fig. 3, there was a significant increase in the perceived discomfort over time. However, no significant differences between the four trials were detected. Increased slops of perceived discomfort were seen over time for all seven body parts. More values of discomfort were recorded for the hip areas. Overall, the average ratings of PLD were less than 3.2 on a scale of 0 to 10 and the discomfort levels were moderate.

[Fig. 3 here]

DISCUSSION

The RMS is an expression of the amplitude of the EMG signal, and it consistently increases during a fatiguing contraction (Strimpakos et al., 2005). Only a few studies

identified the reliability of the RMS in assessing the degree of fatigue, and there was a controversy among researchers regarding the reproducibility of the RMS (Koumantakis, Arnall, Cooper, & Oldham, 2001).

Strimpakos et al. (2005) proposed that the RMS slope was poor to moderate, with a large between-session error limiting its utility in monitoring neck muscle fatigue.

However, De Luca found that an increase in the RMS amplitude could be regarded as an indicator of localized muscle fatigue during repetitive lifting tasks (De Luca, 1997). It is our hypothesis that a decrease in one or more of the frequency domain parameters coupled with a concomitant increase in the time domain parameters would be a reliable indicator of the passenger's discomfort levels. Therefore, in the current study, the RMS and MPF methods were both used to identify whether the fatigue and discomfort could have occurred over the long-term flight. According to the RMS results of the CES, the UT and the LM upward trends were found over time, along with the significant decrease in the MPF analysis. With the above in mind, our hypothesis was strongly supported by the preceding results. The results are consistent with the results of a previous study by Balasubramanian et al (2009).

In the present study, only the CES and the UT were influenced by the factor of the seatback angle, and the CES was significantly affected by seat pitch. No significant difference was found in the LM between each trial, this result did not agree with the finding that indicated that an increased backrest angle was associated with reduced muscle activity in the back muscles when measured by EMG (Knutsson, Lindh, & Telhag, 1966). The reason for this distinction may be because the area of the placement electrode on lumbar multifidus (LM) was in contact with the surface of backrest and the EMG signals could have interference to some extent.

In general, though not statistically significant in nature, slight elevations in RMS levels and negative shifts in MPF values for the cervical, lower back and hip regions were obtained over 120 min sitting in the aircraft seat (see Fig. 1 and Fig. 2). This finding is consistent with the results reported by Kim and Chung (1995), who found that the MPF analysis for trunk muscular fatigue showed good compliance with the EMG amplitude analysis. Moreover, previous studies proved that muscle fatigue caused an increase in the RMS and a decrease in the values of the MPF (Barandun, von Tscharner, Meuli-Simmen, Bowen, & Valderrabano, 2009; Roman-Liu, Tokarski, & Wójcik, 2004). In other words, the muscle fatigue of neck, shoulder and lower back occurred during the 2 h of sitting in the aircraft seat.

Significant increases of MPF for all three muscles were found at 30 min, and then the trend continuously shifted to negative. This phenomenon may be due to the 30 min sitting action leading to perceived discomfort and frequent posture shifts, because a study reported that aircraft passengers adjusts their body positions unconsciously when they feel discomfort (Chow & Odell, 1978). This opinion was supported by previous research, which stated that it took between 30 and 45 min before discomfort or fatigue occurred (Le, Rose, Knapik, & Marras, 2014; Na, Lim, Choi, & Chung, 2005).

In the present study, the MPF results demonstrated that only the CES was significantly influenced by the interaction efforts of seatback angle × seat pitch. Along with the RMS statistical results of the seatback angle × seat pitch interaction effects; this indicated that there were only a few relations between the EMG changes and the different combinations of seatback angle and seat pitch. This issue may need to be studied and discussed further.

The rating of perceived discomfort of the RLB was significantly influenced by the factor of the seatback angle. A 120 °seatback angle was beneficial to the right lower

back regions compared with an angle of 90°. This result is in agreement with a study done by Andersson et al. (1974) and Harrison et al. (2000) who determined that the ideal backrest angle for reducing the EMG of the back during sitting or driving is 120°.

Seat pitch is significantly influenced by the perceived discomfort of the lower backs and hips. The larger seat pitch (34") was more advantageous to the passengers' comfort than the smaller one (30"). Overall, the highest ratings of PLD in lower backs and hips were found in T1 (with a 90° seatback angle and a 30" seat pitch). This indicated that, as outlined above, the enlargement of the seatback angle and seat pitch was conducive to relieving the perceived discomfort (Harrison et al., 2000; Kremser et al., 2012), especially for the lower back and hips.

A line plot revealed that the PLD measurement was more sensitive than the EMG measurement for investigating discomfort in the temporal dimension (see fig. 1-3). This finding was in line with a previous study that showed that subjective analyses were more sensitive than parameters analyzed with the objective measurement recording by EMG and seat pressure distribution (X. Li, Ding, Zhou, Hu, & Zhao, 2014). However, an indication of fatigue was found in the present study during a 2 h sitting session, according to a slight increase in the EMG amplitude and a decrease in the EMG spectrum along with increased perceived discomfort, although these changes were only partially significant. This finding was in line with Quigley et al. (2001) , who indicated that the body discomfort of aircraft passengers was associated with the flight duration.

There are several limitations to the present study. First, the measurements were carried out under laboratory conditions without considering the factors of vibration, noise, cabin pressure, and so forth. Future studies may address comfort changes in vibration and noise. Second, only the muscular activation of the upper extremity was

examined. The muscular activation of the buttocks and lower limbs should be an additional consideration. Third, it remains unknown how muscle fatigue and discomfort develop during a long time sitting in an aircraft seat interspersed with short breaks (standing or walking on the aisle). Fourth, the small sample size may limit the generalization of the results, and the trial needs to be repeated using a larger sample. Finally, the change of posture and joint angle would be an effective way to analyze physical exposure, so that an electrogoniometer or a kinect camera should also be employed to identify muscle fatigue and subjective discomfort (Werth & Babski-Reeves, 2014; Xu & McGorry, 2015).

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TABLE

TABLE I. DESCRIPTIVE STATISTICS FOR THE ROOT MEAN SQUARE (RMS) AND MEDIAN POWER FREQUENCY (MPF) VALUES OF MUSCLE ACTIVITY AND PERCEIVED LEVELS OF DISCOMFORT (PLD) VALUES DURING SITTING IN THE ECONOMY CLASS AIRCRAFT SEAT FOR DIFFERENT COMBINATIONS OF SEATBACK ANGLE AND SEAT PITCH (STANDARD DEVIATION), ALONG WITH THE STATISTICAL RESULTS (P VALUES) OF THE SEATBACK ANGLE, SEAT PITCH AND SEATBACK ANGLE × SEAT PITCH INTERACTION EFFECTS.

	Dependent variable	Combinations of seatback angle (deg) and seat pitch (in)				*p* Values for the main factors		
		90 °/30"(T1)	90 °/34"(T2)	120 °/30"(T3)	120 °/34"(T4)	Seatback angle	Seat pitch	Seatback angle × Seat pitch
RMS data (mV)	CES	0.31(0.32)	0.14(0.11)	0.18(0.22)	0.07(0.05)	**0.004**	**0.000**	0.378
	UT	0.17(0.14)	0.16(0.12)	0.07(0.05)	0.07(0.05)	**0.000**	0.451	0.861
	LM	0.11(0.07)	0.10(0.01)	0.10(0.07)	0.067(0.02)	0.098	0.066	0.358
MPF data (Hz)	CES	76.23(14.41)	81.13(13.54)	82.85(14.32)	76.38(13.96)	0.594	0.655	**0.001**
	UT	77.14(12.03)	79.35(11.97)	80.04(14.37)	81.28(13.01)	0.134	0.285	0.766
	LM	75.74(11.97)	76.08(13.71)	77.96(11.88)	79.56(13.78)	0.078	0.548	0.695
PLD data	NE.	1.15(1.37)	1.07(1.02)	0.97(0.91)	0.76 (1.16)	0.747	0.613	0.187
	LS	0.76(1.16)	0.77(0.91)	0.75(0.71)	0.63(0.66)	0.371	0.562	0.434
	RS	0.69(1.02)	0.67(0.91)	.89(0.84)	0.67(0.77)	0.252	0.170	0.268
	LLB	1.83(1.70)	1.29(1.33)	1.28(1.16)	1.36 (1.17)	0.075	0.107	**0.028**
	RLB	2.00(1.68)	1.32(1.29)	1.31(1.18)	1.38(1.17)	**0.019**	**0.029**	**0.007**
	LH	2.12(1.81)	1.66(1.41)	1.78(1.34)	1.60(1.26)	0.177	**0.029**	0.334
	RH	2.24(1.79)	1.65(1.45)	1.79(1.37)	1.61(1.26)	0.093	**0.010**	0.172

Cervical erector spinae (CES), upper trapezius (UT), lumbar multifidus (LM); neck (NE.), left shoulder (LS), right shoulder (RS), left lower back (LLB), right lower back

(RLB), left hip (LH), right hip (RH); bold values indicate significant differences ($p<0.05$).

FIGURES

Fig. 1. Mean and standard error ratings of the RMS for three muscles, including the cervical erector spinae (CES), the upper trapezius (UT) and the lumbar multifidus (LM), reported over 120 min sitting in the economy class aircraft seat.

Fig. 2. Mean and standard error ratings of the median power frequency (MPF) for three muscles, including the cervical erector spinae (CES), the upper trapezius (UT) and the lumbar multifidus (LM), reported over 120 min sitting in the economy class aircraft seat. No differences were found between each trial over time.

Fig. 3. Mean and standard error ratings of the perceived levels of discomfort (PLD) for seven body parts, including the neck (NE), left shoulder (LS), right shoulder (RS), left lower back (LLB), right lower back (RLB), left hip (LH), and right hip (RH), reported over 120 min sitting in the economy class aircraft seat.

An asterisk (*) indicates a significant difference.

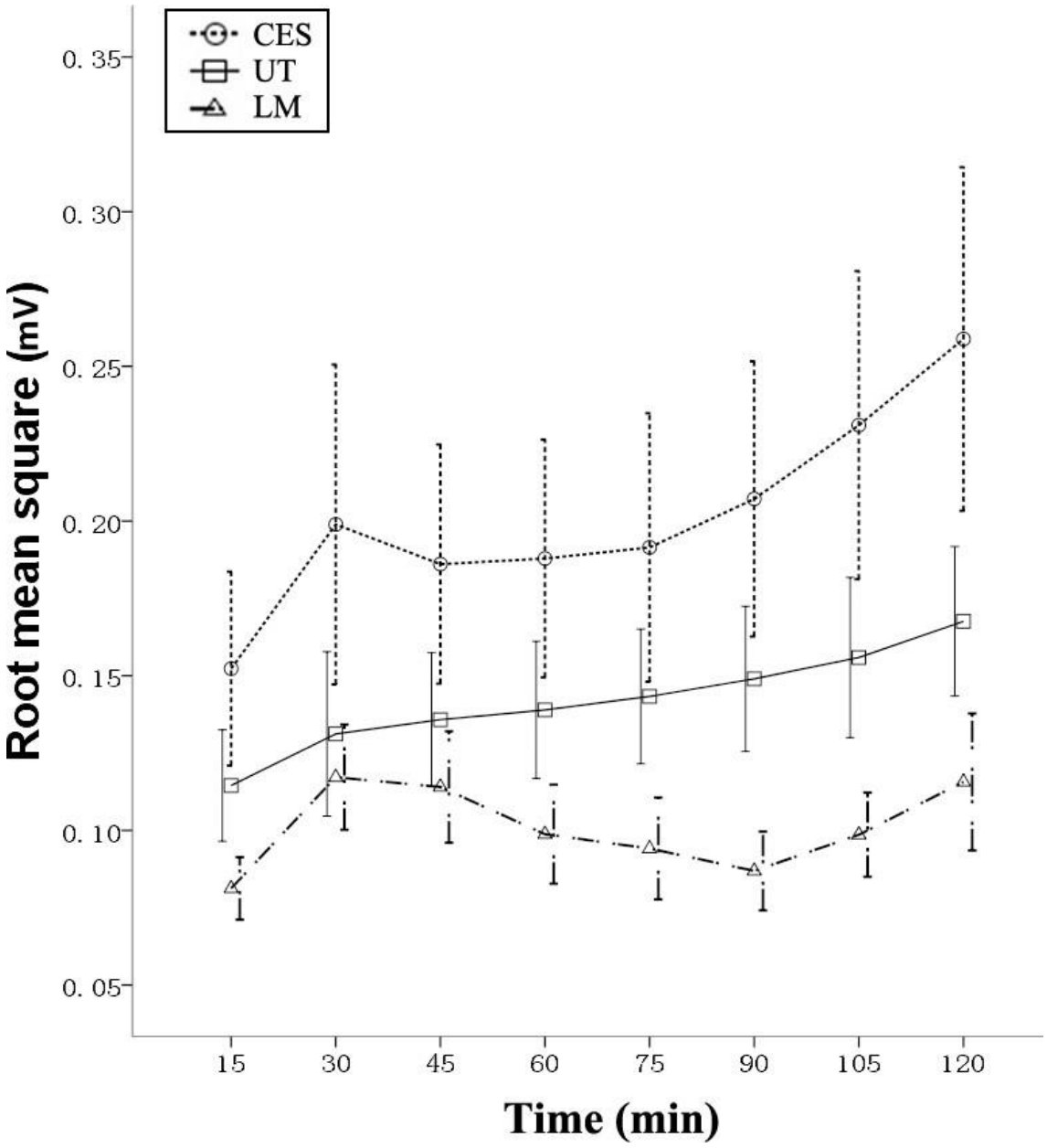


Fig 1. Mean and standard error ratings of the RMS for three muscles, including the cervical erector spinae (CES), the upper trapezius (UT) and the lumbar multifidus (LM), reported over 120 min sitting in the economy class aircraft seat.

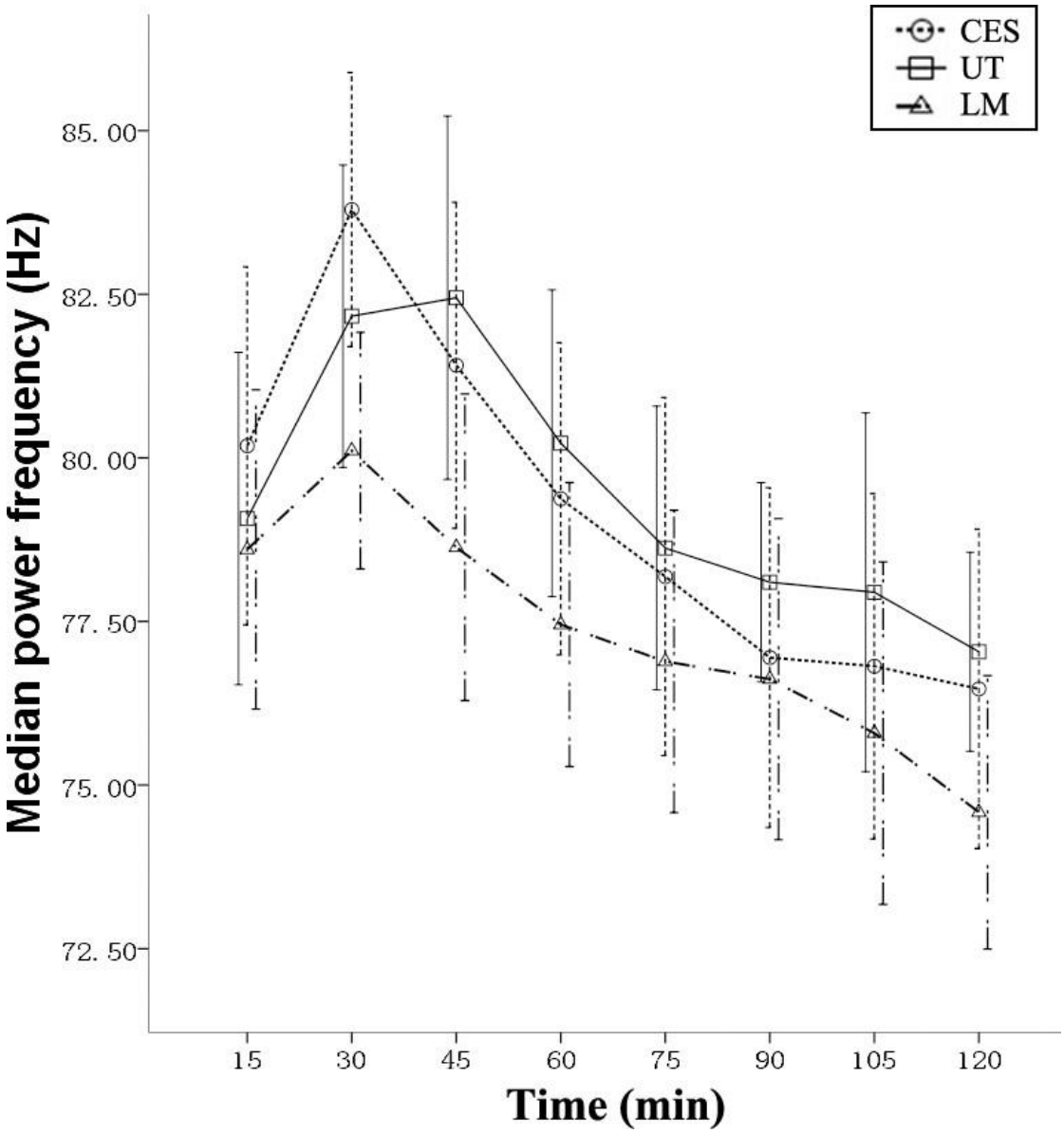
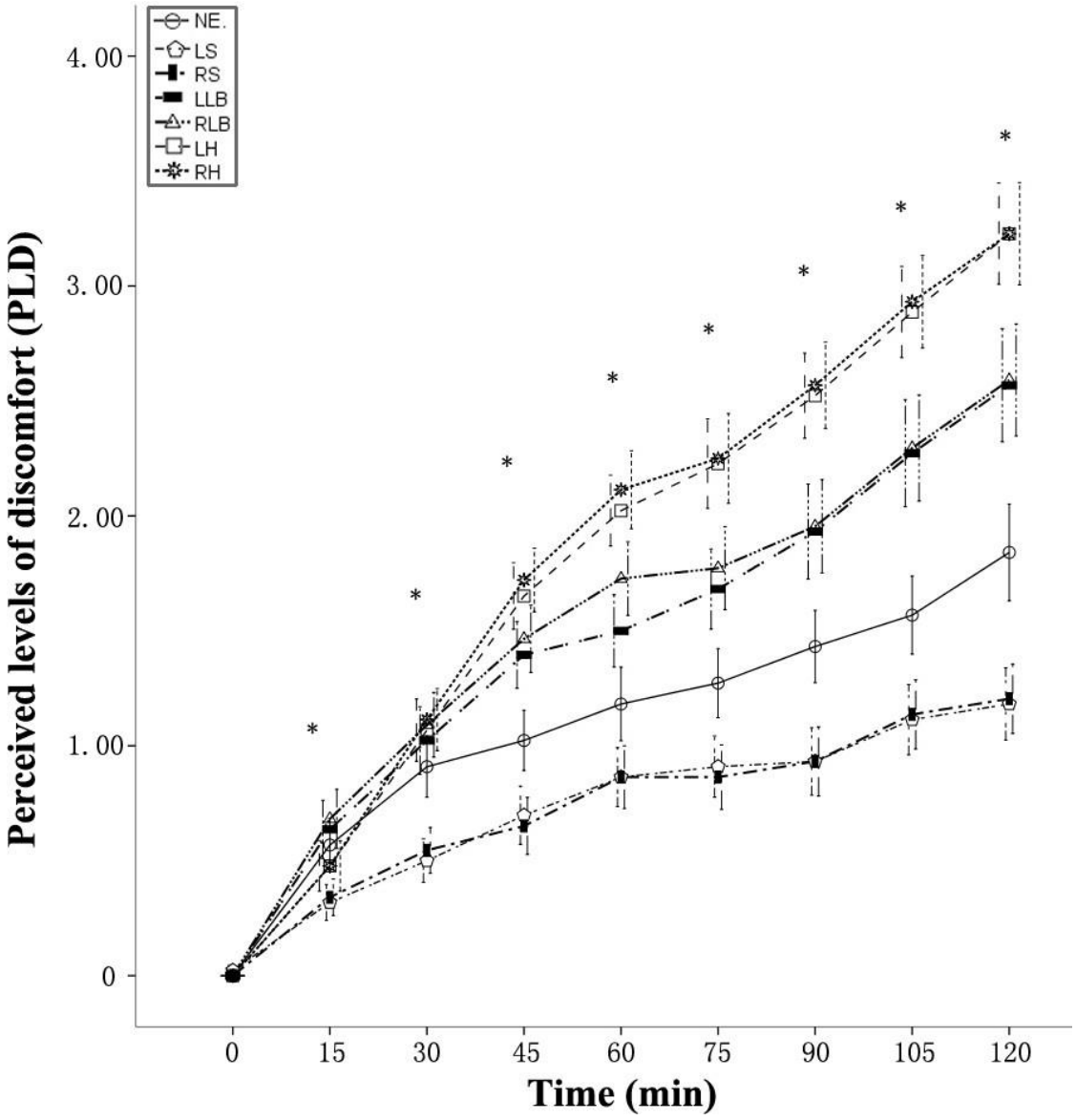


Fig 2. Mean and standard error ratings of the median power frequency (MPF) for three muscles, including the cervical erector spinae (CES), the upper trapezius (UT) and the lumbar multifidus (LM), reported over 120 min sitting in the economy class aircraft seat. No differences were found between each trial over time.



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An asterisk (*) indicates a significant difference.

Chinese Urban Families Kitchen Behavior Process Research based on Naturalistic Observation: Exploring Ergonomic Problems, Coping Strategies and Design Solutions

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Abstract: The kitchen is an important area in the home serving many purposes both functional and social. Chinese urban family Kitchens have narrow but involve complex behaviors. The purpose of this paper is to explore the basic characteristics of users' behaviors in "L-shaped" family kitchens by using the naturalistic observation methods. From the perspectives of staying time, operating line, relationship strength and key human-machine variables, this paper quantitatively studied the behavior characteristics of kitchen users, reconstructs a new "kitchen work triangle" (cooking area-cleaning area-preparation area) of Chinese urban families kitchen, explored ergonomic problems, and puts forward a series of kitchen design strategies and solutions for user operation-centered kitchens that are more adaptable to people's experiencing needs and narrow "L-shaped" space.

Keywords: naturalistic observation; Chinese urban family kitchen; behavior research; kitchen design

1. Introduction

At present, the design and layout of the integrated kitchen in China is mainly based on reference and imitating Western countries, which makes it difficult to fit the narrow kitchen space of the urban families in China (survey statistics show that the number of households with a kitchen area of 5-8 square meters accounted for more than 72%, and the "L-shaped" arrangement accounted for more than 70%)[1]. Also it is difficult to meet the cooking and lifestyle of Chinese families, even aggravating the alienation between family members. In the design process of integrated kitchen, it is an important factor to create a satisfactory kitchen by studying how users interact with products in a real kitchen environment, and to understand the needs and ergonomics of users. Naturalistic observation, as the basic method of collecting behavioral data, is often used to research consumer behaviors, driving behaviors, [2] kitchen life for the elderly[3]and learning processes, which is to explore the behavioral characteristics of users in the real environment. This paper adopts the method of naturalistic observation, taking the kitchen of mainstream households in Chinese as an example to study the behavior characteristics of users in the real kitchen environment. Under the research path, it is possible to quickly obtain reliable user behavior data, explore the complex experience and needs of users, and gain insight into the opportunities of the integrated kitchen design. Besides，it provides a basis for designing an integrated kitchen that meets the narrow space and the needs of complex behaviors for mainstream households in China.

2. Naturalistic observation and Research on User Behavior

Naturalistic observation is, in contrast to analog observation, a research tool in which a subject is observed in its natural habitat and natural context without any manipulation by the observer. During naturalistic observation, researchers take great care to avoid

interfering with the behavior they are observing by using unobtrusive methods. Naturalistic observation involves two main differences that set it apart from other forms of data gathering. In the context of a naturalistic observation, the environment is in no way being manipulated by the observer nor was it created by the observer. By merely observing at a given instance without any manipulation in its natural context, naturalistic observation makes the behaviors exhibited more credible because they are occurring in a real, typical scenario as opposed to an artificial one generated within a lab. In naturalistic observation, the observer does not interfere with the environment at all, not allowed to participate in the incident, and may attempt to interact with the users as little as possible. The observer must remain neutral, not changing anything in the environment beyond.

Industrial design is demands-oriented, so understanding the real needs of users is the basic premise for effective product design. But these needs are usually uncertain variables that depend on the psychology and behaviors of the users. The user's behavior can be briefly defined as the continuous reaction or activity in order to achieve some expected purpose (or subconscious) when users interacting with the outside environments. It is generally believed that user behavior is determined by three factors, including intention, habit and situation,[4] and involves two basic spatial and temporal attributes. The behavior is closely related to the space, which is reflected that user behavior is carried out in a specific space environment. At the same time, a space cannot be called space without human activities. Since Chinese kitchen is a limited space filled with complex behaviors, the division of kitchen space and the arrangement of furniture and equipment must consider and meet users' behavioral needs. In terms of time dimension, user behavior acts on the product components in sequence by different related actions and causes changes in the state of the product structure. Therefore, the

study of behavior requires observing, recording, and describing the key action nodes of user behavior in a specific space environment, analyzing operational processes and action processes, identifying user behavior habits and preferences, and understanding user intent. Ultimately realize the real needs of users in different situations and find opportunities for design innovation.

3. Methods

Research on user behavior usually involves four aspects, specifically recording behavior, defining the variables of behavior, measuring and describing behaviors, and explaining reasons.[5-6] The user behavior research based on natural observations is carried out in the real use situation of family kitchen, and the specific research steps are as follows: [7]

3.1 Recording behavior

Observers select typical users, secure the camera to the tripod, put the camera in a place where observers can effectively photograph the panorama of the kitchen, and tell users about the shooting process and its purpose. Then, researchers shot the videos of whole process from preparation to cooking, cleaning, etc. Moreover, researchers use the videos that recording whole cooking process of a lunch or dinner as the event unit to help analyze users' behaviors.

3.2 Defining behavioral variables

Viewing and analyzing event units, combining qualitative and quantitative analysis, researchers define typical behavior variables based on specific user's kitchen environments（The spatial layout of Chinese domestic kitchen mainly includes cleaning area, preparation area, cooking area, condiments storage area, electrical appliances - kitchenware - food storage area, refrigerator, trash bin and dining table）.

These variables are as follows:

Operation Line: Directed routes for users moving in different areas.

Stay Time: The length of time users spends in different areas.

Strength of Regional Relationship: Describing the number of other kitchen areas (users' behavior) associated with a certain area in the kitchen.

Key Variables of Man-machine Relationship: It is determined that the key human-machine relationship variables in the kitchen operation process contrasted the historical experience and standard human body template. These variables involve waist-bending, knee-bending, elbow-raising, squatting, and leaning forward.

3.3 Measuring and describing behaviors

The plans of kitchen space are drawn according to the layout of user kitchen. Then, the values of relevant variables are measured and the user behaviors are digitalized (as shown in Figure 1) according to videos analyzing. These specific data are as follows:

(1) The operation lines between different kitchen areas according to users' movements in different kitchen areas.

(2) The time spent by users in different areas.

(3) The relationship strength data of each region calculated according to the distribution of operation lines.

(4) The frequencies of key variables of man-machine relationship in different regions.

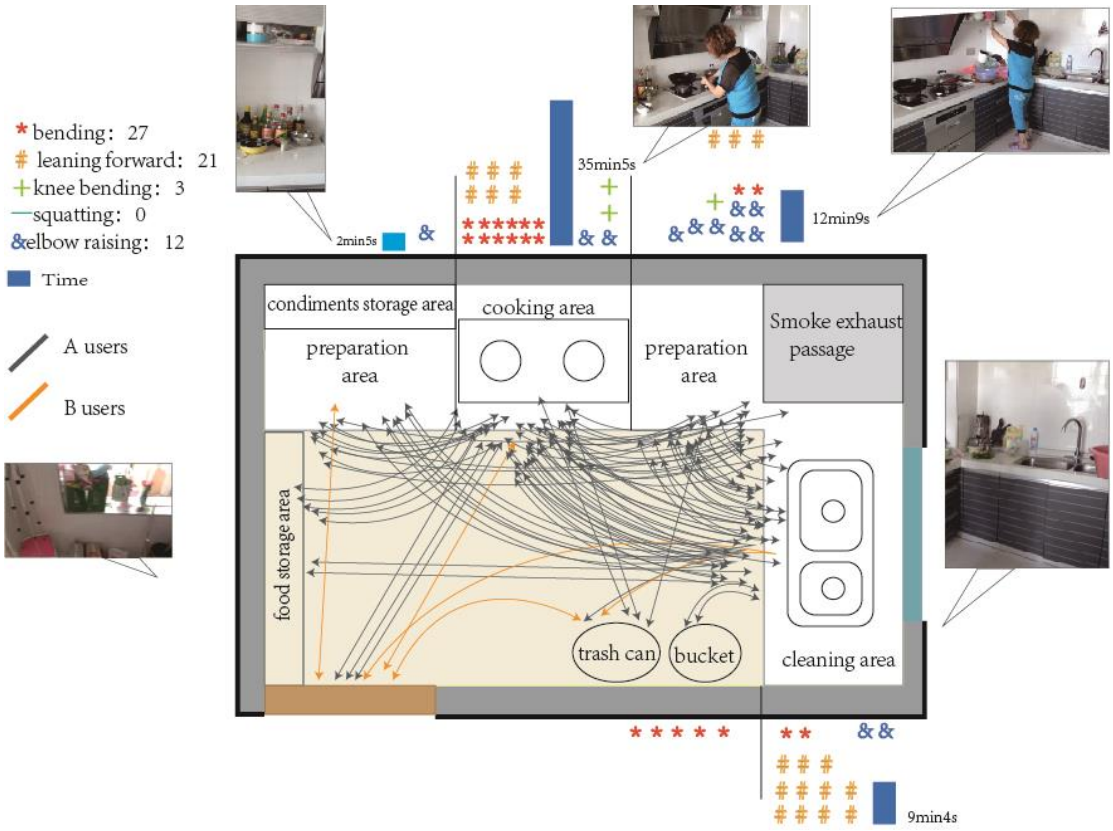

Fig.1 measurement and description of one households' behavior

3.4 Abstracting expression of operation line

Based on the frequency data in Fig. 1, the operating line is simplified (the arrows of lines are removed, and the thickness of the line represents the frequency of the round trip). At the same time, the household plan in Fig. 1 is removed, and the area, moving line and their thickness relations are retained (there is no connection between the areas without moving line). Then, the area nodes are arranged according to the location and logic of the actual kitchen layout. The frequency network diagram of operating line is obtained as shown in Fig. 2.

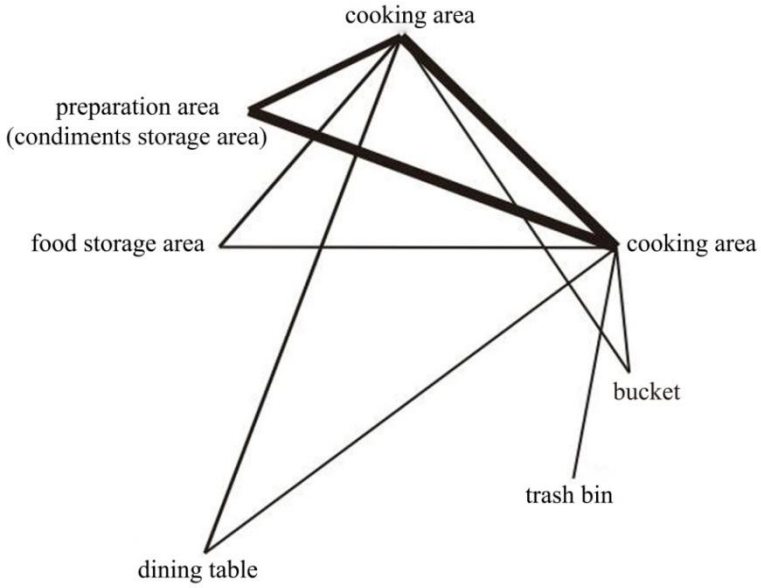

Fig.2 frequency network diagram of one households' operation line

3.5 Data analyzing and behavior interpreting

According to the results of statistics and description, the characteristics of kitchen user behavior variables are analyzed and evaluated. The main concerns are:

(1) According to the thickness distribution of the lines, the user's round-trip frequency between different regions is found.

(2) Discovering the relationship between the lengths of time users stay (work) in each area, so as to determine the key work area.

(3) Determining the "busy area" of the kitchen, that is, the area with high intensity of strength of regional relationships.

(4) Analyzing the main reasons for users' bad experience in different regions according to the frequency data key variables of man-machine relationships, such as waist-bending, knee-bending, elbow-raising, squatting, and leaning forward.

4. Results

A total of 23 families with “L-shaped” kitchens were investigated in this study, and four researchers counted and analyzed the data. The statistical data of various behavioral variables are as follows: [7]

4.1 Stay Time

In kitchen activities, due to the difference of tasks, the length of stay time in each functional area is different. After statistics and analysis of video capture data, the average stay time of each functional area is shown in Table 1.

Tab.1. the average length of stay time in each area（minutes）

Areas	cook	clean	preparation	kitchenware	food	appliance	condiment -storage	trash bin	refrigerator
Stay Time	23.04	19.26	13.83	4.17	0.78	1.39	6.65	1.09	0.96

The statistical data show that the users stay longer in the three areas of cooking, cleaning and preparation. And the sum (56.13 minutes) of these three areas’ stay time is close to 80% of the total time (71.17 minutes).The cooking area takes the longest time, followed by the cleaning area and the preparation area. Since the height of the space occupied by the cleaning area which installed stoves and pans and the cooking area with sink is not consistent. In the traditional “L-shaped” kitchens, the unified table height design referenced to the preparation area is not the optimal solution, because this design ignores the length of the user's stay time in the cooking area and cleaning area and the height characteristics of the two areas.

4.2 Operation line

In the activities of the kitchen, the operation lines describe the degree of correlation

between functional areas during the completion of kitchen tasks. Through statistics and analysis of video data, the frequency of operation lines of users with "L-type" Kitchen in each functional area is shown in figure3. It can be seen from figure3, the most frequent trips are between the cleaning area, cooking area, and preparation area. Users also travel more frequently between condiment areas and tables, but the frequency of commuting to and from the refrigerator is low during the whole cooking process. This is very different from the traditional western Frankfurt Kitchen process. In the process of kitchen activities of Frankfurt Kitchen, users have the most contacts among refrigerators, cleaning area (pool) and cooking area (stove). And the triangle formed by the line between these three areas constitutes the traditional "kitchen work triangle".

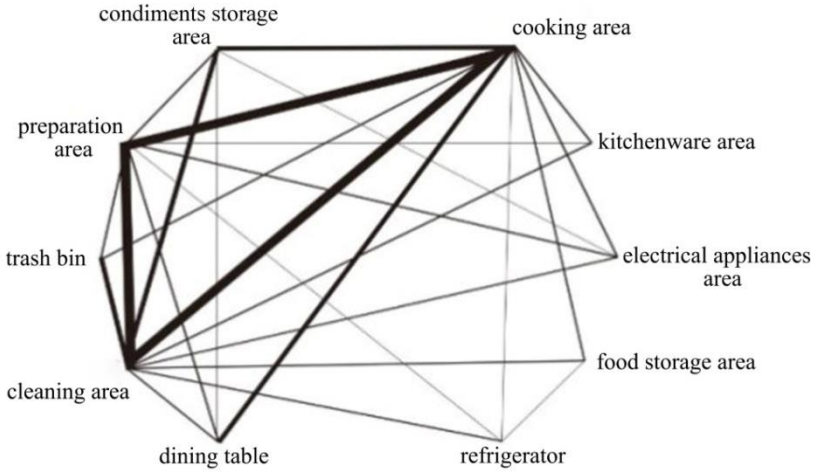

Fig.3. frequency network diagram of average households' operation lines in "L-shaped" kitchen

4.3 Strength of regional relationship

The relationship strength between functional areas in kitchen is very complex. According to the frequency network diagram of average households' operation lines in "L-shaped" kitchen, the schematic diagram of the relationship strength of each functional area is constructed as shown in Figure 4. In this figure, blocks of different colors represent different kitchen regions, the height and numbers of the color blocks

represent the strength of the relationship between the regions. And the color blocks are arranged and laid out according to the actual location relationship and logic of the area in the kitchen. And connections represent operation lines between regions, and overlapping colors represent overlap of round-trip actions. From Figure 4, it can be seen that the intensity of the relationship between cleaning area and cooking area has been very prominent, followed by preparation area. Cleaning area, cooking area and preparation area are still the busiest traffic areas in the kitchen, and there are contacts with them of all of the kitchen areas. In traditional Chinese kitchens design, cooking and preparation areas have always been the focus of attention, while cleaning areas are often neglected.

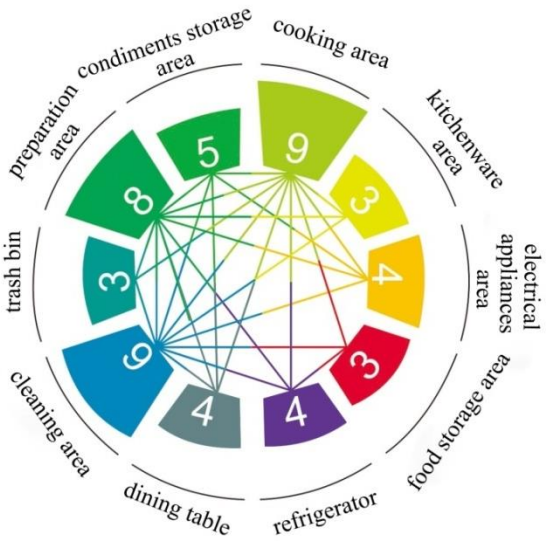

Fig.4. Strength of regional relationship diagram of "L-shaped" kitchen

(average frequency less than 0.5 times out of the statistical range)

4.4 Key Variables of Man-machine Relationship

The distribution of key man-machine variables (average value) in each region is shown in figure 5. As can be seen from figure 5, the cooking area, cleaning area and preparation area are the areas with the most concentrated distribution of key human-

machine variables. During the observation, from the point of view of movement distribution, it was found that the main reason for elbow lifting is to pick up things from the hanging cabinet, and the main reasons for the forward leaning and bending are cleaning the water tank and observing the flame of the gas stove. And it was also found that the main reasons for knee bending and squatting are to find and pick up articles in disinfection cabinets and floor cabinets.

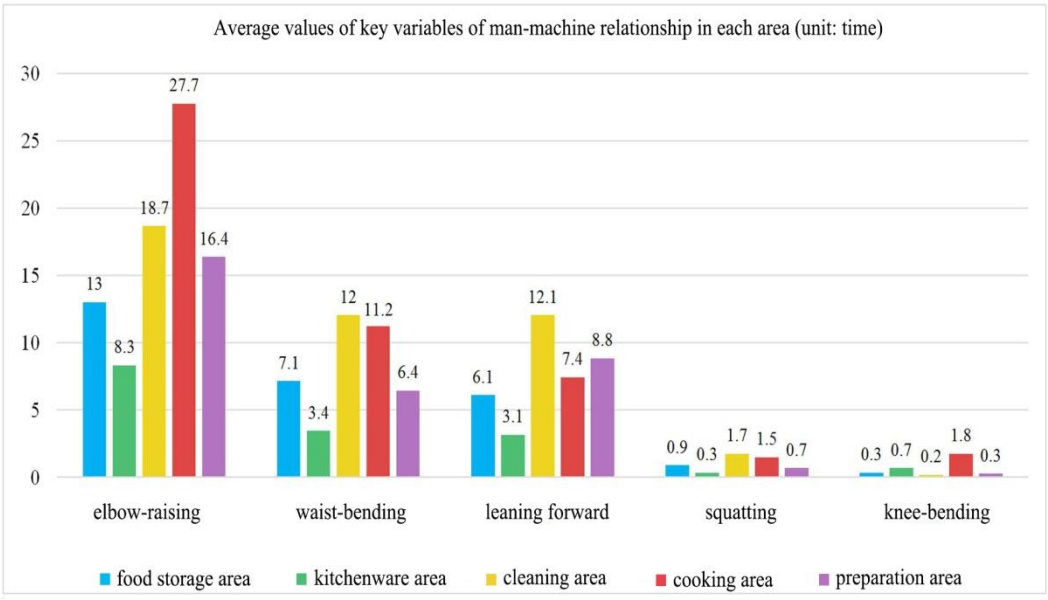

Fig.5. The distribution diagram of key variables of man-machine relationship (average values)

5. Strategies and Solutions

5.1 Characteristics of behavior process

According to the characteristics of each behavioral variable in the course of Chinese urban kitchen behavior, the area and characteristics of the behavior of kitchen users were summarized. According to the relationship between the regions and objects of the behavior and its role, the basic goals of the regional layout and product (object) design (as shown in the table 2) were outlined, and the design strategy and specific solutions

were further proposed according to the design goals. The proposal of the goal is based on three basic principles:

（1）It conforms to the behavior habits of Chinese users when cooking, such as frequent operation lines, areas of long stay, etc.

（2）Improve the efficiency of kitchen work through innovative design or optimal design.

（3）Through innovative design or optimal design, reduce actions that do not meet the friendly relationship between humans and machines, and further improve the comfort of operation.

Tab.1. characteristics of behavior process and design targets for "L-shaped" family kitchens

Behavioral variables		***Characteristics***	***Design targets***
Operation Line		1)most frequent trips are between the cleaning area (pool), cooking area (stove), and preparation area. 2) ding table, condiments storage area and trash bin are very important more than refrigerator.	optimization of area layout design,1)highlight the close interaction among the new "kitchen work triangle". 2) support for inter-regional relations among ding table, condiments storage and trash bin. 3) reducing distance requirements between refrigerators and core areas.
Stay Time		1) spending most time in three areas of cooking, cleaning and preparation. 2) cooking> cleaning> preparation	1) consider three areas of cooking, cleaning, and preparation when optimizing human-machine relationships. 2) add some of these areas.
Strength of Regional Relationship		1) cleaning area and cooking area has been very prominent. 2) then preparation area.	1) optimization of area layout design, highlight the close interaction among he new "kitchen work triangle". 2) add some of these areas.
Key Variables of Man-machine Relationship	*waist-bending*	mainly in cleaning and cooking area.	1) optimization height of kitchen cabinets and countertops. 2) optimization width of countertops, 3) optimization of function area layout.
	knee-bending	mainly in cooking area.	
	elbow-raising	mainly in cleaning, cooking and preparation area.	
	squatting	mainly in cleaning and cooking area.	
	leaning forward	mainly in cleaning, cooking and preparation area.	

5.2 Behavior process characteristics oriented design strategies and solutions

From the perspectives of the length of stay time, the frequency of operation lines and the strength of regional relationship among different areas, cooking area, cleaning area and preparation area are the key areas in Chinese kitchen, and these areas constitute a new "working triangle of Chinese kitchen", which should be considered as the core factors in overall kitchen layout design, regional size planning and so on. Among the three areas, cooking areas and cleaning areas have the longest stay time and the busiest area with the strongest strength of regional relationships. Therefore, in the kitchen layout design, the solution of "hot and cold double cooking area" (fig. 6) and two water systems (fig. 7) was proposed, which can satisfy the simultaneous operation of many people, and is also an effective solution to solve the high frequency, long time and frequent communication between cooking area and cleaning area with other areas. At the same time, considering the close relationships between condiments and cooking and meal preparation, we can design a condiment bottle storage area between the preparation area and the cooking area to facilitate the sharing of cooking and preparation.

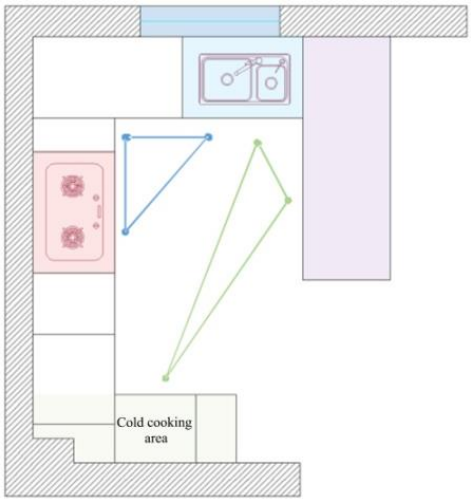

Fig.6. “cold- hot” double cooking area solution of kitchen China Shangpin Company

Fig.7. "Double Sinks" solution in kitchen Italian Miton Company

5.3 Key man-machine variables oriented design strategies and solutions

In terms of key human-machine variables, elbow-raising frequently is due to the height of hanging cabinet when taking or searching items. With a traditional depth of 600 mm, wall cabinets are too close to your face, giving you a close-in feeling. Wall cabinets have to be at least 540 mm high above the countertop for best visibility, but that makes it hard for you to see inside and get what you need. When the table is widened (if it reaches 800mm), we can consider adding a drainage machine behind the counter, which not only facilitates the collection of dishes, but also reduces the key man-machine variables such as waist-bending, squatting and knee-bending caused by putting bowls and chopsticks in the sterilizing cabinet (as shown in Figure 8).

When the user works, if the bottom of the cabinet does not leave more space for the user's feet, or the height of the operating table is not enough, the user needs to lean forward. In order to reduce the leaning forward and waist-bending variables, it is reasonable to adopt sufficient concave and a certain height of kick line, or to adopt a supporting structure (as shown in Figure 9). At the same time, according to the user's

height, the cleaning area (concave), preparation area and cooking area (convex pot) of the kitchen cabinet are designed to be three layers: high, medium and low, which can also reduce the times of leaning-forward, waist-bending and elbow-raising.

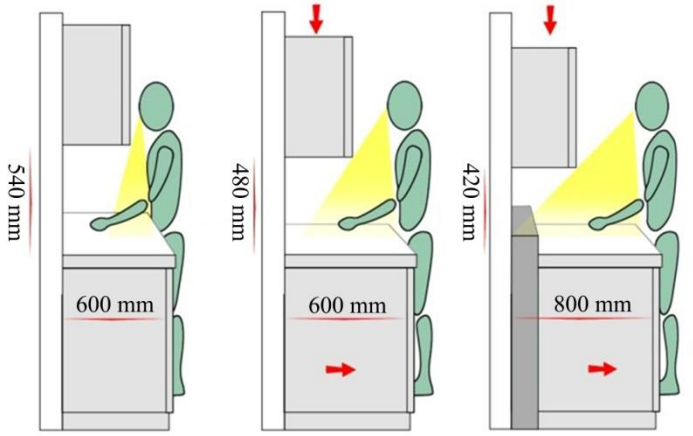

Fig.8. Solutions by widening countertop and reducing hanging cabinet

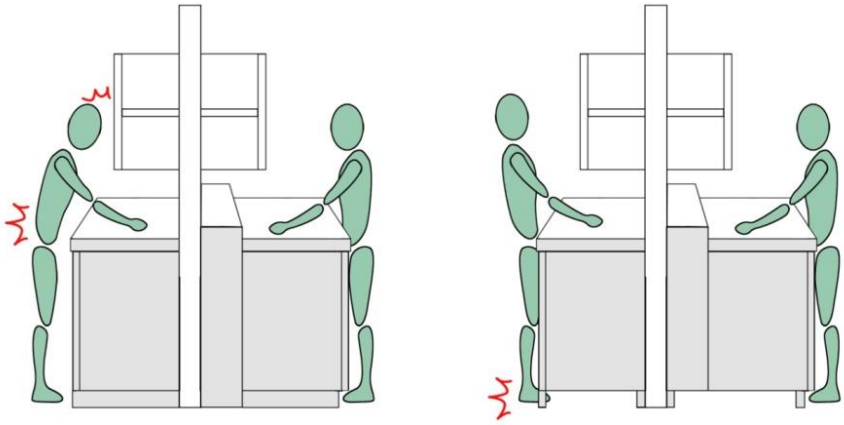

Fig.9. Solutions by kicking line or supporting structure

6. Conclusions

The research of kitchen user's operation behavior based on naturalistic observation can effectively discover the user's behavior rules and real demands in the real kitchen situation, and serve as the guide of product design, help designers optimize product experience, discover the original opportunity of product, make the developed product more in line with user's operation habits and experience, and truly solve the problem.

User-centered design is supported by solving ergonomic problems in users' operation. However, naturalistic observation also comes with disadvantages in this research, such as the sample size provided is limited, each cooking process is unique and lacks of universality, and there are some uncontrolled observer biases. These disadvantages may reduce the generality and generalization of behavioral variable data. [8] Therefore, in the process of user behavior research, some investigation methods such as interviews should add to further improve the effectiveness and reliability of naturalistic observation.

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How Do Users Accept A New Technology: Face Recognition Payment System Acceptance Model Research

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Abstract: The objective of this study is to examine the user's adoption aspects of face recognition payment, as well as to investigate what factors drive people to adopt face recognition. A Model explaining the impact of different factors on face recognition payments intention is developed based on the technology acceptance model (TAM)and Unified theory of acceptance and use of technology (UTAUT). A survey of 415 users was conducted and the result were analyzed using partial least squares. The results demonstrated that perceived usefulness and perceived ease of use are major important determinants of intention to use face recognition payment. The result also shows that three constructs—Subject norm, System quality and Perceive Enjoyment —have an indirect positive effect on behavioral intention, in the study identified that perceive risk has a negative effect on behavioral intention.

KeyWords： face recognition payment； mobile payment； technology acceptance model；use study

1 Introduction

In recent years, artificial intelligence has become a hotspot of competition technology in the world's major developed countries. China has achieved good results in research and development of new technologies and industrial applications in the field of artificial intelligence, and the number of related patent applications continues to grow(B. Li, Hou, Yu, Lu, & Yang, 2017).Especially in face recognition, the face recognition technology developed by Baidu, Ali, Tencent and other companies has high recognition accuracy and fast speed, and has achieved leading results in world-class competitions many times(L. Li, 2018). As a representative of the development of new modes of the new digital economy in China, mobile payment has become a research hotspot in academic circles in recent years. Especially the user acceptance behavior related to mobile payment is the focus of experts and scholars.

Based on the technology acceptance model, this study summarizes the characteristics of face recognition technology through literature review, research, interviews, etc. and introduces it as an impact variable into the technology acceptance model (TAM), from system quality, subjective norms, expectations. A technical acceptance model for face recognition is constructed in terms of risk and so on(Qingjie & Hanshi, 2018). A face recognition technology acceptance survey scale was developed and a questionnaire survey was conducted. Using the valid sample data of 415 questionnaires, the validity and reliability of the questionnaire were verified by exploratory factor analysis. The structural equations and multiple linear regression analysis methods were used to analyze the path relationship between the variables. The research finds that the technology acceptance model for face recognition technology can predict the user's behavior intention well and has certain research value. It can provide reference for designing recognition systems from the perspective of users in the future.

2. Theoretical Basis

Applying the existing technology acceptance model in the field of human-computer interaction to the field of face recognition authentication without adjustment is problematic.(Flandorfer, 2012) Because face recognition authentication is an unprecedented technology(Turkle, 2017). In this chapter, we review several of the most commonly accepted technology acceptance models and analyze the pros and cons of these models. These models provide a theoretical basis for us to propose a technical acceptance model for the face recognition payment system.

2.1 Technology Acceptance Model（TAM）

In the field of human-computer interaction, scholars have put forward various viewpoints from different perspectives on the use of technology by human beings. It is considered that users face information technology and information systems are not passively accepted, but in the environment and individuals. Under the influence of various factors, choose to accept or reject new technology. The Technology Acceptance Model (TAM) was proposed by studying the user's acceptance and use behavior(F. Davis, 1989).

TAM assumes that the behavioral intention determines the actual use behavior, and the behavioral intention is determined by the individual's practical attitude and usefulness perception. At the same time, ease of use perception has a direct impact on usefulness perception, and usefulness perception also has a direct impact on behavioral intentions(Fred D. Davis, 1996).TAM does not include any adjustment variables, and all factors affecting belief are summarized by external variables. Scholars who criticize TAM clearly point out that TAM does not include the influence of regulatory variables(Bagozzi & Yi, 1988); Davis found through formal research that with the

increase of experience, ease of use cognition is no longer a significant variable(F. Davis, 1989); Venkatesh also found that usefulness cognition is more important for men in technology adoption decisions, and ease of use cognition is more important for women(Venkatesh & Morris, 2000).

The criticism of TAM is divided into three aspects. (1) Dishaw and Strong believes that it is unreasonable to abandon subjective norms in TAM, because users of information technology will receive the influence of leaders, colleagues, friends, and family members, especially in In a collectivist cultural environment, users are more inclined to refer to the opinions of others(Dishaw & Strong, 1999).(2) TAM does not fully consider the control factors. Ajzen proposes that behavioral intentions are influenced by attitudes and subjective norms. Opportunities, resources, and control capabilities also affect behavioral intentions (Ajzen, 1985).（3）Self-determination theory believes that people's behavioral motives can be seen as one In the continuous process of internal motivation from external motivation to external motivation, TAM only considers external motivation and does not include internal motivation factors.

2.2 Unified Theory of Acceptance and Use of Technology

In fact, although there are differences in the expression of various theoretical models, the essence is the same, and because of the complexity of behavioral research and the perspective of each researcher, no theory can contain all the influencing factors. Therefore, the theoretical community urgently needs to integrate various user acceptance models.

Based on this, Venkatesh et al. successfully integrated the 32 main elements and four adjustment variables in each model as the determinants of behavioral intention and behavior, and proposed the theory of technology acceptance and utilization

integration(Venkatesh & Morris, 2000). UTAUT consists of four core variables: performance expectance, Effort Expectance，Social Influence and Facilitating Condition，and four regulatory variables: gender, age, experience, and voluntary.

UTAUT is criticized for not being parsimonious enough, because it requires several variables to achieve a substantial level of explained variance(Venkatesh & Morris, 2000). Parsimony, the goal of which is to identify factors accounting for the most variation, is to be greatly valued(Venkatesh & Morris, 2000), but not at the expense of explanatory power. UTAUT does not explain the different underlying mechanisms, although such an explanation would make the unified model more suitable for explaining the user's general opinions about expected use, rather than explaining the user's motivations relating to the continued and increased adoption of a particular technology (Peters, 2011).

2.3 TAM Extension

Based on a large number of techniques to accept model validation studies, Wixom & Todd (2005) summarizes three extensions of the model: 1 introducing variables in related models, such as subjective meals, perceived behavioral control, and self-efficacy; 2 introducing belief variables, mainly Is a key factor in the innovation diffusion model, such as compatibility, visibility, results display, etc.; 3 the introduction of external variables, as a pre-variable of usefulness cognition or related variables, such as personality characteristics, demographics feature(Wixom, Todd, Wixom, & Todd, 2005).

3 Theoretical model and research hypothesis

The relationship between the user and the face recognition payment system is the interaction between the user and the product. Therefore, this study draws on the relevant

research results of the technology acceptance model to study and explain the user's acceptance behavior of the face recognition payment system.

The technology acceptance model believes that usefulness cognition affects users' behavioral intentions toward information technology(de Graaf, Ben Allouch, & van Dijk, 2019). A large number of experimental studies have also confirmed the significant influence of usefulness cognition on behavioral intentions.

This study suggests that for users, their perceived usefulness will directly affect their behavioral intentions caused by face recognition authentication(Schepers & Wetzels, 2007), so the hypothesis is:

H1: Perceived usefulness has a positive direct impact on behavioral intentions, that is, the more users think that face recognition payment is useful to themselves, the stronger the willingness to use the system.

The technology acceptance model argues that ease of use affects users' usefulness in understanding new technologies, and the easier it is to use the system, the more useful the system is(F. D. Davis, Bagozzi, & Warshaw, 1989). A large number of studies have also confirmed ease of use. Direct impact on usefulness perception (Moon & Kim, 2001).

H2: Perceived ease of use has a positive direct impact on usefulness cognition, that is, the more users think that a certain payment method is easy to use, the more useful it is.

A large number of studies have confirmed the direct impact of ease of use on behavioral intentions(Agarwal, 1999; Venkatesh & Morris, 2000). Therefore, this study considers that the perceived ease of use will directly affect its behavioral intentions for product use.

H3: Perceived ease of use has a positive direct impact on behavioral intentions, that is, the more users think that a payment method is easy to use, the stronger their willingness to use

Subjective norm refers to an individual who perceives that an important person thinks he should or should not perform an action. Rational Behavior Theory (Ajzen, 1985) and Planned Behavior Theory. Ajzen argues that subjective norms directly influence the user's behavioral intentions. When a more important person in a certain environment thinks that the system should be adopted, the user will obey his point of view and adopt the system. Subjective norms achieve a direct impact on usefulness perception through both identification and internalization(Yu Data, Eveleigh, Shlomo Berkovsky, Ronnie Taib, & Zhou, 2019). Therefore, for the user, this study believes that subjective norms will affect the user's usefulness and behavioral intentions of payment methods, and make assumptions:

H4: Subjective norms have a positive direct impact on usefulness cognition. When users perceive that the surrounding environment believes that a search engine should be adopted, users will consider face recognition payment useful.

H5: Subjective norms have a positive direct impact on behavioral intent, that is, when the user perceives that the surrounding environment believes that a certain payment method should be adopted, the user will form an intention to use face recognition payment.

The most influential research field in the field of information system quality evaluation is the information system success model proposed by DeLone and McLean(1992).It was further improved in 2003. Many studies have used system quality as an external variable for usefulness cognition and ease of use. The results of the study confirm the direct impact of system quality on user beliefs. For search engines, the

quality of their systems affects users. Internal motivation and ease of use awareness. Therefore, this study believes that users' perception of the quality of the face recognition payment system will affect the user's usefulness and ease of use. propose assumption:

H6: System quality cognition has a positive direct impact on usefulness cognition, that is, when users perceive the higher quality of payment methods, their usefulness will be stronger.

H7: System quality cognition has a positive direct impact on ease of use cognition, that is, when the user perceives that the quality of the payment method is higher, the perceived ease of use will be stronger.

Davis, Bagozzi and Warshaw argue that when choosing to adopt a new technology, users not only consider the value of the tool as a tool, but also the degree to which the user feels happy during use, so the factors that influence the user's acceptance of the new technology include internal motivation. And external motivation (Delone & Mclean, 1992).

H8: Perceived enjoyment has a positive direct impact on ease of use cognition, and the user's ease of use cognition becomes stronger when the user perceives pleasure in use.

Perceived risk is a major construct for predicting behavioral intention in various information technology studies. Further, studies have confirmation that perceived risk negatively influences behavioral intention(Choi & Ji, 2015). In the context of face recognition payment, it is also expected that perceived risk negatively influences behavioral intention. Therefore, we hypothesize:

H9：Perceived risk has a negative effect on behavioral intention.

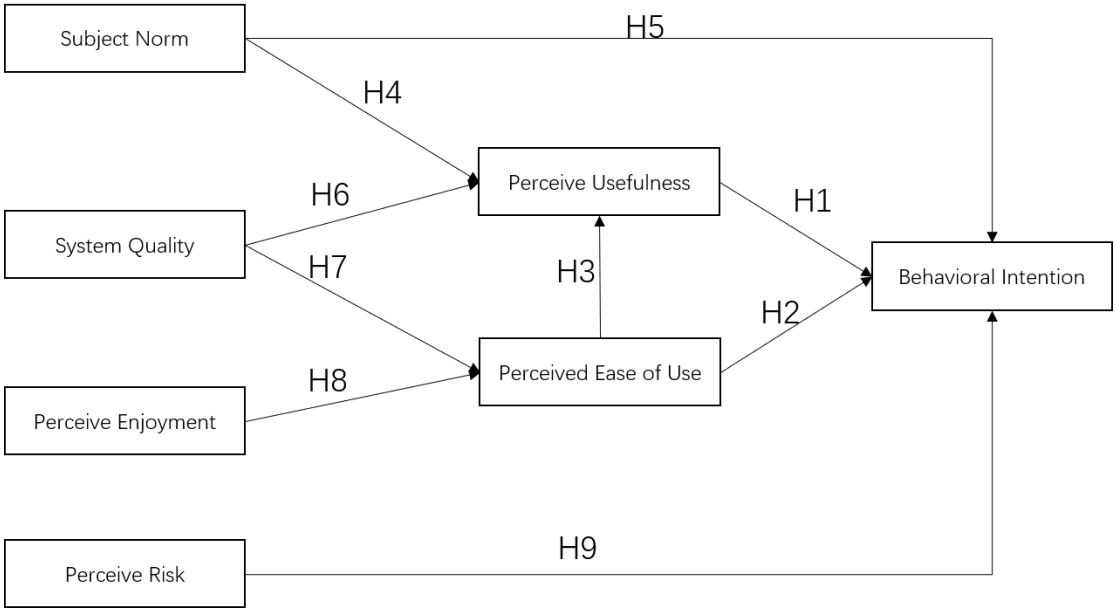

Figure 1. Research model

4. Variable Measurement and Data Collection

4.1 Survey Design

In order to understand the factors that affect the user's willingness to pay for face recognition, it is preliminary verified whether the model is reasonable. Based on the maturity scale and expert opinion feedback in the relevant research, this paper constructed a pre-study questionnaire containing 26 measurement items, and issued 110 copies, a total of 92 copies were collected. According to the analysis results of the pre-study experiments, PU4 with overlapping semantics was removed. The formal questionnaire has 20 measures. Measurements were made using a likert 7 scale.

4.2 Data Collection

The formal questionnaire for this study was conducted online, and the respondents were those who had experienced the use of face recognition payment. A total of 415 copies of the actual valid questionnaires were distributed. The effective rate of the questionnaire

was 83%. The demographic description shows that 48.4% of the men

Table 1： List of Constructs and Their Items

Construct		Item
Behavioral	BI1	I intend to use face identify payment in the future.
	BI2	I expect that I would use face recognition payment in the future.
	BI3	I plan to use face recognition in the future.
Perceived Usefulness	PU1	Using autonomous vehicle will increase my productivity.
	PU2	Using autonomous vehicle will increase my driving performance.
	PU3	Using autonomous vehicle would enhance my effectiveness while driving.
Perceived Ease of use	PEOU1	For me, learning how to use face recognition payment devices is easy
	PEOU2	I can easily use the features provided by the face recognition payment device.
	PEOU3	When using the face recognition payment device, the human-computer interaction is clear and easy to understand.
	PEOU4	In general, this face recognition payment device is easy to use.
Subject norm	SN1	My friends or classmates have a high opinion of face recognition payments.
	SN2	I will use face recognition to pay for publicity.

	SN3	Since people around me use face recognition to pay, I will use it too.
Perceived enjoyment	PE1	I am satisfied with the results of using face recognition payment
	PE2	I like to pay with face recognition payment.
	PE3	I am happy to use it when I need to make a payment.
	PE4	The process of using face recognition payment is enjoyable.
System Quality	SQ1	I think face recognition payment is a powerful tool.
	SQ2	I think the face recognition payment system has a higher quality.
	SQ3	I am very satisfied with the service provided by the face recognition payment system.
	SQ4	For the face recognition payment system, my evaluation is excellent.
Perceived Risk	PR1	Face recognition Payment would lead to a financial loss for me
	PR2	Face recognition payment might not perform well and create problem.

participated in the survey, 51.6% of the females, and the gender ratio was balanced; the young people were the subject of the survey; the education level was relatively high, and the undergraduate and above education level was 86.3%. On the whole, it can basically cover the young people.

Statistical analysis of demographic characteristics（N=415）

Table 2

Item	Classification	Frequency	Percentage
Gender	Male	201	48.4%
	Female	214	51.6%
Age	≤18	44	10.6%
	18-25	152	36.6%
	25-30	177	42.6%
	31-40	76	18.3%
	≥40	57	13.7%
Education background	High school and below	17	4.1%
	Specialist	43	10.3%
	Bachelor	221	53.2%
	Graduate and above	134	32.2%

4.3 Data analysis

In this paper, SPSS20 and LISREL8.8 are used to analyze the reliability and validity of the data, and the model hypothesis is tested by using the structural equation model.

5. Result

5.1 Data Analysis of measurement Model

The measurement model should be assessed before the structural model is examined. The measurement model can be assessed based on internal consistency, convergent validity, and discriminant validity (24 Barclay, Higgins, & Thompson, 1995).

Cronbach's alpha is used to validate internal consistency, and 0.7 or higher is recommended. Item loadings are recommended to exceed 0.6 (Hair, 2006). The composite reliability values are recommended to exceed 0.7. The average (AVE) value for each latent variable should exceed 0.5, and the square root of the AVE should be greater than the interconstruct correlations.

Table 3: Scales for Reliability and Convergent Validity

Construct		Loading	SD	Loading	α	CR	AVE
Behavioral	BI1	0.70			0.82	0.82	0.54
	BI2	0.82					
	BI3	0.77					
Perceived usefulness	PU1	0.77			0.81	0.83	0.62
	PU2	0.85					
	PU3	0.75					
Perceived Ease of use	PEOU1	0.75			0.82	0.84	0.59
	PEOU2	0.82					
	PEOU3	0.74					
	PEOU4	0.79					
Subject Norm	SN1	0.59			0.76	0.77	0.53
	SN2	0.80					
	SN3	0.77					
Perceived	PE1	0.89			0.86	0.86	0.68
	PE2	0.85					

enjoyment	PE3	0.72				
	PE4	0.54				
System quality	SQ1	0.78		0.93	0.93	0.7
	SQ2	0.79				
	SQ3	0.88				
	SQ4	0.83				
Perceived Risk	PR1	0.75		0.76	0.82	0.66

Table 4: Correlation Matrix and Discriminant Validity

Construct	BI	PU	PEOU	SN	PE	SQ	PR
BI	0.75						
PU	0.48	0.56					
PEOU	0.56	0.45	0.73				
SN	0.11	0.54	0.45	0.84			
PE	0.47	0.45	0.41	0.31	0.78		
SQ	0.23	0.53	0.43	0.33	0.41	0.76	
PR	-0.29	-0.15	-0.23	-0.14	0.02	0.22	0.82

As shown in table 3, all item loadings exceed 0.6. All AVEs are larger than 0.5. The composite reliability and Cronbach's alpha exceed 0.7. These results show a good reliability and convergent validity (Bagozzi & Yi, 1988).

To assess discriminant validity, we compared the square root of AVE for each factor to its correlations with other factors. As we can see from Table 2, the square root of AVE for each factor is obviously larger than its correlation coefficients with other factors. Thus, the scale has a good discriminant validity (Fornell & Larcker, 1981; Gefen & Straub, 2000). In addition, the correlation value between latent variables are

lower than 0.7, so multicollinearity issues were avoided. Thus, the measurement model was proven to be reliable and valid for the study.

Data Analysis of the Structural Model

Table 5 lists all path coefficients and their significance. A t test was conducted to the significance of path coefficients based on significance level 0.5. All hypotheses are supported expects H7 and H9.

Perceived usefulness and perceived ease of use in TAM have a positive impact on willingness to use, with perceived usefulness having the greatest impact, with a path coefficient of 0.32. The impact of perceived ease of use is relatively small, and the path coefficient is 0.27. Perceived ease of use has a positive impact on perceived usefulness, with a path coefficient of 0.35. The results verify hypotheses H1, H2 and H3.

Subjective norms have a positive impact on behavioral intention and perceived usefulness, with path coefficients of 0.41 and 0.23. This verifies H4 and H5.

System quality has a positive impact on perceived usefulness, with a path factor of 0.32. This verifies H6. Pleasant cognition has a positive effect on perceived ease of use, with a path coefficient of 0.41. This verifies H8.

Table5: Structural Model Result

Hypothesis	Path	b	T Value	Support or Not
H1	PU→BI	0.32	3.99	Support
H2	PEOU→BI	0.27	3.76	Support
H3	PEOU→PU	0.35	4.31	Support
H4	SN→PU	0.41	2.22	Support
H5	SN→BI	0.23	2.22	Support
H6	SQ→PU	0.32	3.69	Support

H7	SQ→PEOU	0.11	0.14	Not Support
H8	PE→PEOU	0.41	5.52	Support
H9	PR→BI	-0.19	-3.06	Support

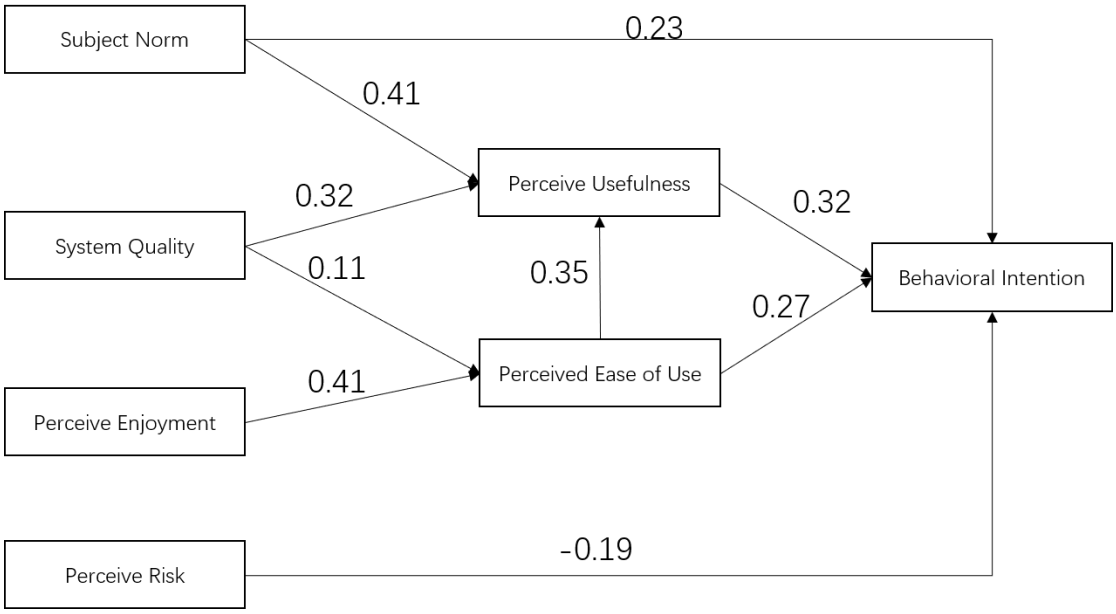

Figure 2. Assessment of the structural model

5.2 Limitations

This research has some limitations. First, the respondents were not perfectly controlled: The age was not balanced. The number of respondents from 20 to 39 years of age is relatively higher than the number of other respondents. Thus, the results could be biased toward younger men's opinions. Second, the model clearly does not include all relevant variables. Future researches should test the possible inclusion of other external variables (e.g., personality characteristics). Therefore, more researches are needed to validate, expand, and generalize these results.

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