Title	Gender-specific associations of depression and anxiety symptoms with mental rotation
Author(s)	押山, 千秋
Citation	大阪大学, 2018, 博士論文
Version Type	VoR
URL	https://doi.org/10.18910/70697
rights	
Note	

（博士論文表紙様式）

Gender-specific associations of depression and anxiety symptoms with mental rotation

（　うつと不安の程度がメンタルローテーションに及ぼす性差特有の影響　）

大阪大学大学院
大阪大学・金沢大学・浜松医科大学・千葉大学・福井大学
連合小児発達学研究科
小児発達学専攻

押　山　千　秋

２０１８年６月　博士学位論文

Gender-specific associations of depression and anxiety symptoms with mental rotation

Chiaki Oshiyama[a,e,h,*], Chihiro Sutoh[b], Hiroyasu Miwa[c], Satoshi Okabayashi[d], Hiroyuki Hamada[b], Daisuke Matsuzawa[b,e], Yoshiyuki Hirano[a,e], Tetsuya Takahashi[f], Shin-ichi Niwa[g], Manabu Honda[h], Kazuyuki Sakatsume[i], Takuichi, Nishimura[j], Eiji Shimizu[a,b,e]

[a]United Graduate School of Child Development, Osaka University, Kanazawa University, Hamamatsu University School of Medicine, Chiba University, Fukui University, Yamadaoka, Suita, Osaka Japan

[b]Department of Cognitive Behavioral Physiology, Graduate School of Medicine, Chiba University, 1-8-1, Inohana, Chuo-ku, Chiba 269-0856, Japan

[c]Human Informatics Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), AIST Waterfront, 2-3-26, Aomi, Koto-ku, Tokyo 135-0064, Japan

[d]Department of Fashion Sociology and Sciences, Bunka Gakuen University, 3-22-1, Yoyogi, Shibuya-ku, Tokyo 151-8523, Japan

[e]Research Center for Child Mental Development, Chiba University, 1-8-1, Inohana, Chuo-ku, Chiba 260-0856, Japan

[f]Health Administration Center, University of Fukui, 3-9-1, Bunkyou, Fukui 910-0017, Japan

[g]Aizu Medical Center, Fukushima Medical University, 21-2, Tanizawa-Maeda, Kawahigashi, Aizuwakamatsu, Fukushima 969-3482, Japan

[h]Department of Functional Brain Research, National Institute of Neuroscience, National Center of Neurology and Psychiatry NCNP), 4-1-1, Ogawa-Higashi, Kodaira, Tokyo 187-8553, Japan

[l]Faculty of Education and Integrated Arts and Sciences, Waseda University, 1-6-1, Nishi-Waseda, Shinzyuku-ku, Tokyo 169-8050, Japan

[j]Artificial Intelligence Research Center, National Institute of Advanced Industrial Science and Technology (AIST), AIST Waterfront, 2-4-7, Aomi, Koto-ku, Tokyo 135-0064, Japan

Abbreviations: mental rotation response time (RT), mental rotation correct answer rate (CR), major depressive disorder (MDD), the 9-item Patient Health Questionnaire (PHQ-9), the Generalized Anxiety Disorder 7-item scale (GAD-7), analysis of variance (ANOVA).

Highlights

- Men had a significantly higher correct answer rate for the mental rotation task, but no gender difference in response time was found.
- There was no difference in terms of depressive and anxiety symptom intensity in men and women.
- Task response time correlated positively with intensity of depressive symptoms and anxiety in women, but not in men.
- Depressive symptom level did not influence response times in men, only women, and depressive symptom induced the delays in response time of mental rotation task in only women.

Abstract

Background

Men score higher on mental rotation tasks compared to women and suffer from depression and anxiety at half the rate of women. The objective of this study was to confirm the gender-specific effects of depression and anxiety on mental rotation performance.

Methods

We collected data in non-experimental conditions from 325 university students at three universities. Participants completed rating scales of depressive and anxiety symptoms, and then simultaneously performed a mental rotation task using tablet devices.

Results

We observed no significant difference between men and women in the depressive and anxiety symptoms and task response time. Men had a significantly higher correct answer rate compared with women. The scores of depression and anxiety of all participants were positively correlated. Task response time correlated positively with intensity of depressive symptoms and anxiety in women, but not in men. Women with high depressive symptoms had significantly longer response times than did women with low depressive symptoms, while men had no differences due to depressive symptoms.

Limitations

We did not directly examine brain functions; therefore, the underlying neurobiological results are only based on previous knowledge and action data.

Conclusions

The pathology of depression and anxiety was reflected in the correct answer rate and response time in relation to the gender difference of brain function used in mental rotation.

Keywords

Anxiety; depression; gender differences; mental rotation; tablet device; visual working memory.

1. Introduction

Mental rotation is a cognitive function whereby objects, images, and the body are mentally rotated (Kosslyn et al., 1998). Mental rotation enables one to judge contexts through viewing figures or letters from rotated angles. For example, it can be used to view a map from different angles or text from the opposite direction, enabling one to glean greater meaning from these objects without rotating one's body. The mental rotation task is a well-established paradigm for studying the underlying cognitive processes of this ability (Kikuchi et al., 2017).

Notably, men who scored higher than did women on mental rotation tasks (Levine et al., 2016). Mental rotation is typically evaluated in terms of the correct answer rate (CR) and response time (RT). Previous studies have suggested that the CR of mental rotation shows a gender difference: men were significantly more successful than were women in the mental rotation performance (Cohen's d = .50–1.28). Additionally, this gender difference increased with the rotational load (Levine et al., 2016). As for RT, in depressed patients, RT was related to the speed of exercise preparation (Rogers et al., 2002).

Men suffered from depression and anxiety at half the rate of women (Rosenfield, 1999), so, several studies have explored the relationship between mental rotation and affective disorders such as depression and anxiety. Men with low mental rotation ability and high anxiety tend to show poor performance in map-based route learning (Thoresen et al, 2016). A study examined anxiety and mental rotation ability and found that high anxiety degraded mental rotation performance (Kaltner and Jansen, 2014). In a study on a group of patients with recurrent depression, RT was significantly delayed, and this difference was more pronounced in women than in men (Chen et al., 2013).

The ability to use the forward internal model for the mental prediction of motor behavior may be compromised among patients with major depressive disorder (MDD) (Bennabi et al., 2014). The forward internal model is related in the sensory preprocessing loop of control in the central nervous system that employs internal models in motor control (Mehta and Schaal, 2002). Activation of motor-related brain areas is regarded as the central mechanism generating motor imagery (Hanakawa et al., 2008). A wide range of brain regions appear to be activated during a mental rotation task, including those related to motor behavior and motor imagery (Tomasino and Gremese, 2016).

Mental rotation training may activate a wide range of neural networks including those of basal ganglia, occipital and parietal lobes (Berneiser et al., 2016). This suggests that mental rotation tasks, such as those involving the hand, could help train motor imagery as well. When performing rotational transformation of mental rotation, the posterior parietal lobe is activated (Thompson and Kosslyn, 2000). A recent study showed that the posterior parietal cortex is activated during cognitive restructuring (Sutoh et al., 2015), a technique used in cognitive behavioral therapy to reduce anxiety and improve depressive symptoms (Beck et al., 1985; Leahy, 2003). Accordingly, mental rotation training might help to reduce depression and anxiety due to brain crossover effects. However, the relationship between altered affective states and mental rotation merits further investigation. The objective of this study was to assess the gender-specific associations of the intensity of depressive and anxiety symptoms on mental rotation performance.

2. Methods

2.1. Participants

We requested the cooperation of undergraduate and graduate students in four disciplines (fashion design, education, medicine, and engineering) from three of our affiliated universities. We obtained the written consent to participate in this study (including performing the mental rotation test and completing the questionnaire survey) from 325 individuals. We ultimately excluded a student who did not perform the mental rotation test but did answer the questionnaires, as well as two students without complete datasets. The analysis proceeded with a total of 322 students (144 men, 178 women). Handedness was determined for all participants using the Japanese version of the FLANDERS handedness questionnaire (Okubo et al., 2014). Of the 322 students, 280 (87%) were right-handed and 42 (13%) were left-handed. This study received approval from the Chiba University Ethics Committee (approval number: 2261) and was conducted according to the principles outlined in the Declaration of Helsinki.

2.2. Scales

Participants completed two questionnaires and performed a mental rotation task on a tablet device (iPad mini 2; Apple Inc., USA). As the period for data collection was rather limited (it took place after classes at the university), the questionnaires needed to be simple. In addition, because we were evaluating depression and anxiety, we decided to adopt questionnaires that adhered to the diagnostic criteria of the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders: namely, the 9-item Patient Health Questionnaire (PHQ-9) and the Generalized Anxiety Disorder 7-item scale (GAD-7).

The PHQ-9 was created by Spitzer et al. (1999) to measure depression. It utilizes a 4-point Likert scale (Not at all, Several days, More than half the days, and Nearly every day). Total scores were assigned the following meanings: 0–4 indicated no depressive symptoms, 5–9 indicated minor symptoms, 10–14 indicated moderate symptoms, 15–19 indicated moderate to severe symptoms, and 20–27 indicated severe symptoms. The diagnostic cut-off score for depression is 10. The GAD-7 is a 7-item scale, created by Spitzer et al. (2006), that also uses a 4-point Likert scale. The guidelines of the National Institute for Health and Care Excellence recommend it as an assessment tool for generalized anxiety disorder. Total scores were assigned the following meanings: 0–4 points indicated no anxiety symptoms, 5–9 indicated mild symptoms, 10–14 indicated moderate symptoms, and 15–21 indicated severe symptoms. As with the PHQ-9, the cut-off score is 10 (indicating the presence of clinical degree of anxiety).

2.3. Procedure

After participants provided their written consent to participate, they completed a sheet on demographic information (e.g., gender, age, and affiliation), the two measurement scales (PHQ-9 and GAD-7), and a trial of the mental rotation task using the tablet. Data were collected over six days between May and July 2016 at each university for approximately 20 minutes after class. We distributed the surveys and tablets immediately after each class, and explained how to operate the tablet for the mental rotation task. Fifty tablets were prepared, and all participants carried out the mental rotation task at the same time.

For the mental rotation task, we used an application developed by the National Institute of Advanced Science and Technology. The task aimed to measure mental rotation ability in the context of everyday life rather than in an experimental context. To perform the task, participants held both sides of the tablet with their hands. When they thought that the picture on the tablet depicted their right hand, they answered with the right thumb; when they thought that the picture was of the left hand, they answered with their left thumb (see Figure 1 and Supplementary File 1). The mental rotation task consisted of a test trial and a main trial. The purpose of the test trial was for participants to learn how the tablet operated, whereas that of the main trial was to obtain the study data. Students were allowed to perform the test trial as many times as they wished until they felt comfortable with operating the tablet; then, they performed the main trial.

In a preliminary study, 10 of the hand pictures were found to have high CR (left dorsal 0^{o} [twice], right dorsal 0^{o} [twice], left side from thumb 0^{o}, right side from thumb 0^{o}, left side from thumb 90^{o}, right side from thumb 90^{o}, left dorsal 90^{o}, and right dorsal 90^{o}; see Figure 1).

In the main trial, following the guidelines by Cooper and Shepard (1975), Parsons (1994), Conson et al. (2013), and Chen et al. (2014), we randomly presented 32 of the hand pictures (4 limb positions: dorsal, palm, side from little finger, and side from thumb; 4 rotation angles: 0º, 90º, 180º, and 270º; two-handed, left-handed, and right-handed).

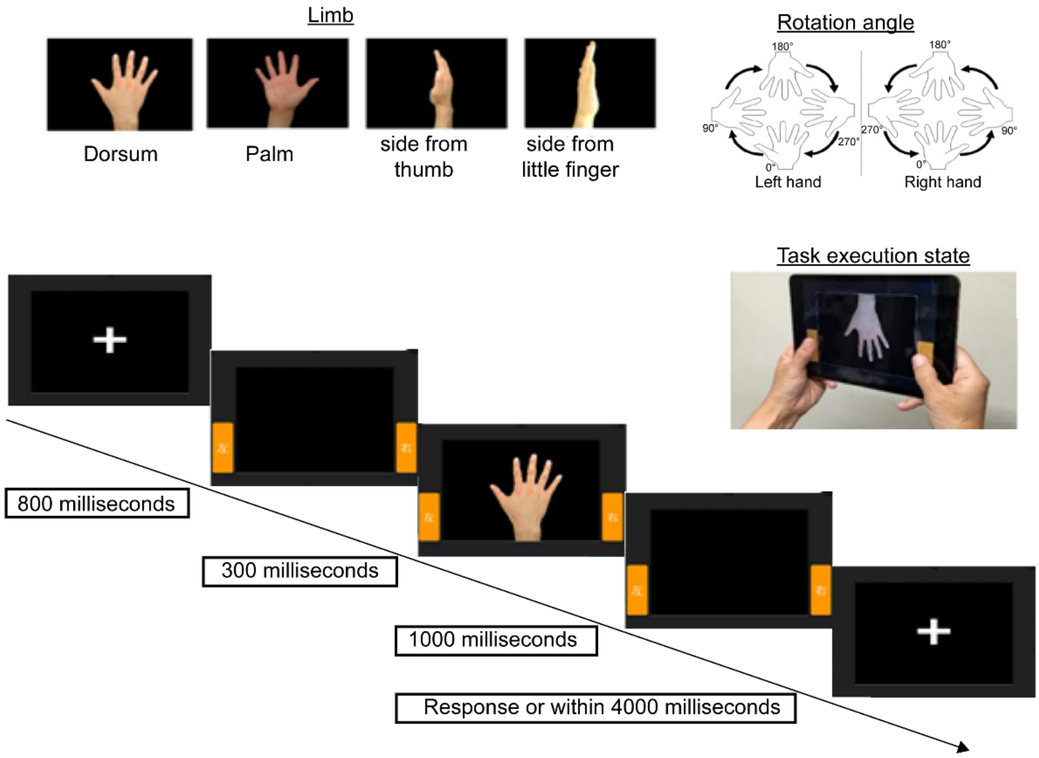


Figure1

2.4. Data processing method

The SPSS Statistics 23 (IBM Corp., Armonk, NY, USA) was used for the data analysis. First, after confirming the reliability of the scales using confirmatory factor analysis, we calculated the means and standard deviations. Spearman's correlation coefficients were calculated between the intensities of depressive and anxiety symptoms and mental rotation performance. Next, we conducted a two-way analysis of variance (ANOVA) and carried out multiple comparisons using the Tukey-Kramer method (5% level) for RT and the PHQ-9 and GAD-7. Because the overall CR and the CR at 0°, 90°, 180°, and 270° were not normally distributed, non-parametric tests including the Mann-Whitney *U* test (for overall CR), Friedman's test (for CR at 0°, 90°, 180° and 270°), and we carried out the multiple comparisons using the Steel-Dwass method. The participants were divided by gender and intensity of depressive and anxiety symptoms based on the median total score of the PHQ-9 and GAD-7. Because the data were asymmetrical and platykurtic skewed, we chose the median as the dividing point for these symptom groups (Manikandan, 2011). Following this, the one-way ANOVA for RT and the Kruskal-Wallis test for CR were performed to determine whether there were any differences in mental rotation task performance between the genders in each symptom group. Differences in mental rotation task performance at each rotation angle were also examined between groups divided with gender and depressive/anxiety symptom intensity using a two-way repeated-measures ANOVAs and and the Kruskal-Wallis test.

3. Results

3.1. The reliability of the scales, mental rotation results, and gender differences

For the PHQ-9, the confirmatory factor analysis revealed that the single-factor structure was a good fit to the data, explaining 39.77% of the variance. The internal consistency was Cronbach's $\alpha = 0.85$. A single factor explaining 35% of the variance was also extracted for the GAD-7. The internal consistency was Cronbach's $\alpha = 0.77$. The means and standard deviations for all variables are shown in Supplementary File 2.

We then examined differences in all variables between men and women using two-way ANOVAs with gender as the independent variable and RT (Supplementary File 2 and Figure 2B), PHQ-9 scores, and GAD-7 scores (Supplementary File 2 and Figure 2A) as the dependent variables. We also conducted a two-way repeated-measures ANOVA for RT at 0°, 90°, 180°, and 270°, and the aforementioned non-parametric tests for MC_CR and MC_CR at 0°, 90°, 180°, and 270° (Supplementary File 2 and Figure 2C).

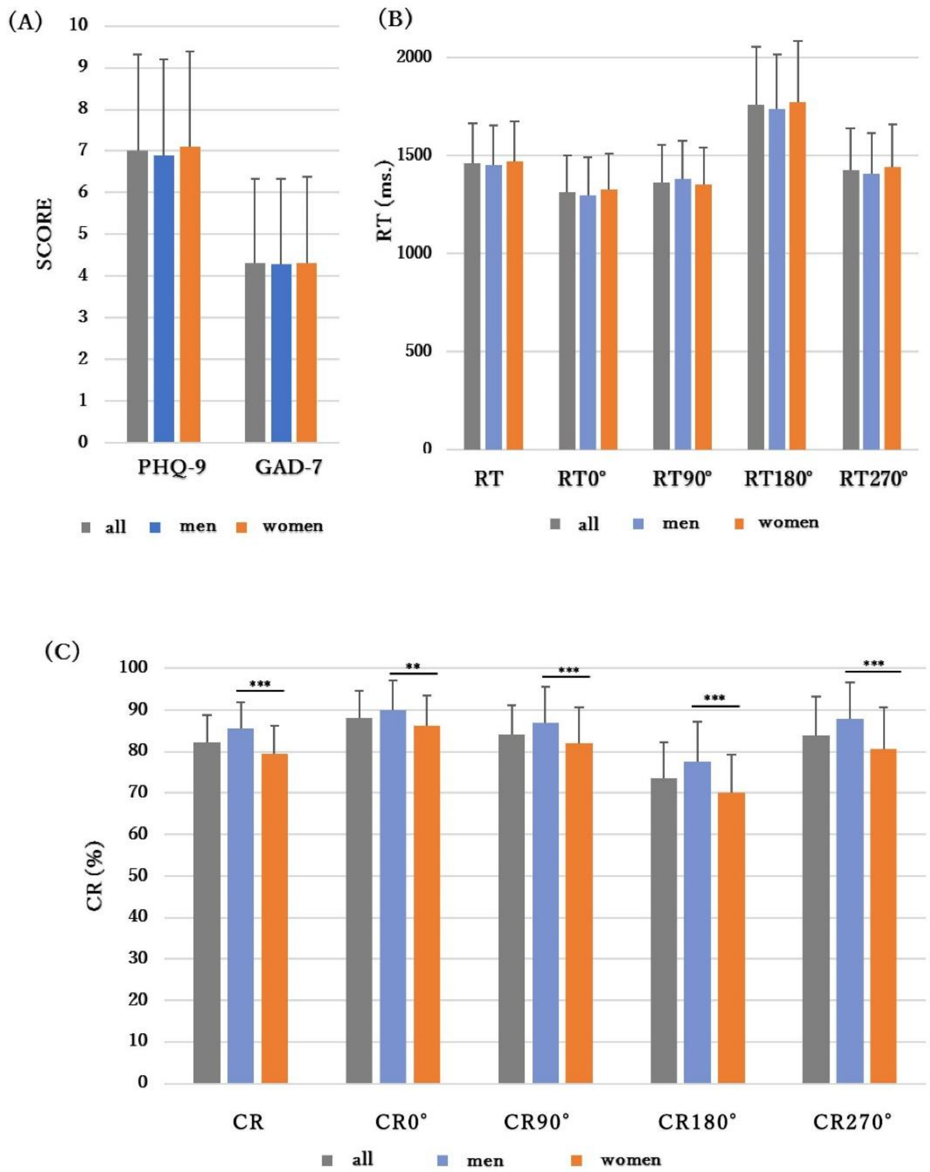


Figure2

3.2. Correlational analysis between scales

The PHQ-9 and GAD-7 of all participants were positively correlated. The RT and the intensity of depressive/anxiety symptoms were significantly correlated only in women (Table 1).

Correlational Analysis Between Each Variable and Gender Differences

	Total (n = 322)			Men (n = 144)			Women (n = 178)		
	CR	PHQ-9	GAD-7	CR	PHQ-9	GAD-7	CR	PHQ-9	GAD-7
RT	0.270***	0.184**	0.135*	0.261**	0.074	0.080	0.314***	0.269***	0.181*
CR		0.027	-0.003		0.40	0.014		0.046	-0.019
PHQ-9			0.677**			0.680***			0.677***

Note. RT = response time, CR = correct answer rate, PHQ-9 = 9-item Patient Health Questionnaire, GAD-7 = Generalized Anxiety Disorder 7-item scale. *$p < .05$, **$p < .01$, ***$p < .001$.

Table1

3.3. Comparison of mental rotation performance according to depressive/anxiety symptom intensity (high or low) and gender

The mean PHQ-9 of all participants was 7.01 with an SD of 4.38 and a range of 0-25. To study the effect of depression on mental rotation by gender, we divided participants into high and low depression groups (with the high group comprising those with a score of ≥6 and the low group those with a score ≤5), and then further divided them by gender. Thus, four groups were created. There was a significant difference in the RT [$F(3,318) = 3.687$; $p = .012$]. Women in the high depressive symptom group had a significantly longer RT than did women in the low depressive symptom group ($p = .008$, Hedge's g = .48) (Figure 3a).

The results in CR indicated a significant difference between these groups ($\chi^2 = 20.398$; $df = 3$, $p < .001$). In the high depressive symptom group, men had significantly higher CR than did women ($p < .01$, $r = 0.40$). Furthermore, in men in the high depressive symptom group had significantly higher CR than did women in the low depressive symptom group ($p < .01$, $r = 0.51$); notably, men in the low depressive symptom group also had significantly higher CR than did these women ($p < .01$, $r = 0.43$), as well as women in the high depressive symptom group ($p < .05$, $r = 0.33$) (see Figure 3b).

The mean GAD-7 of all participants was 4.30 with an SD of 4.13 and a range of 0-20. We performed the same analysis for level of anxiety (with the high group comprising those with a score of ≥4 on the GAD-7 and the low group those with a score of ≤3). For the RT, There was no significant differences among the 4 groups [$F(3,318) = 2.333$; $p = .074$] (see Figure 3c).

As for the CR, we found a significant difference among the groups ($\chi^2 = 20,271$; $df = 3$, $p < .001$). In the high anxiety symptom group, men had significantly higher CR than did women ($p < .01$, $r = 0.33$). Furthermore, in men in the high anxiety symptom group had significantly higher CR than did women in the low anxiety symptom group ($p < .01$, $r = 0.63$); notably, men in the low anxiety symptom group also had significantly higher CR than did these women ($p < .01$, $r = 0.58$), as well as women in the high anxiety symptom group ($p < .05$, $r = 0.33$) (see Figure 3d).

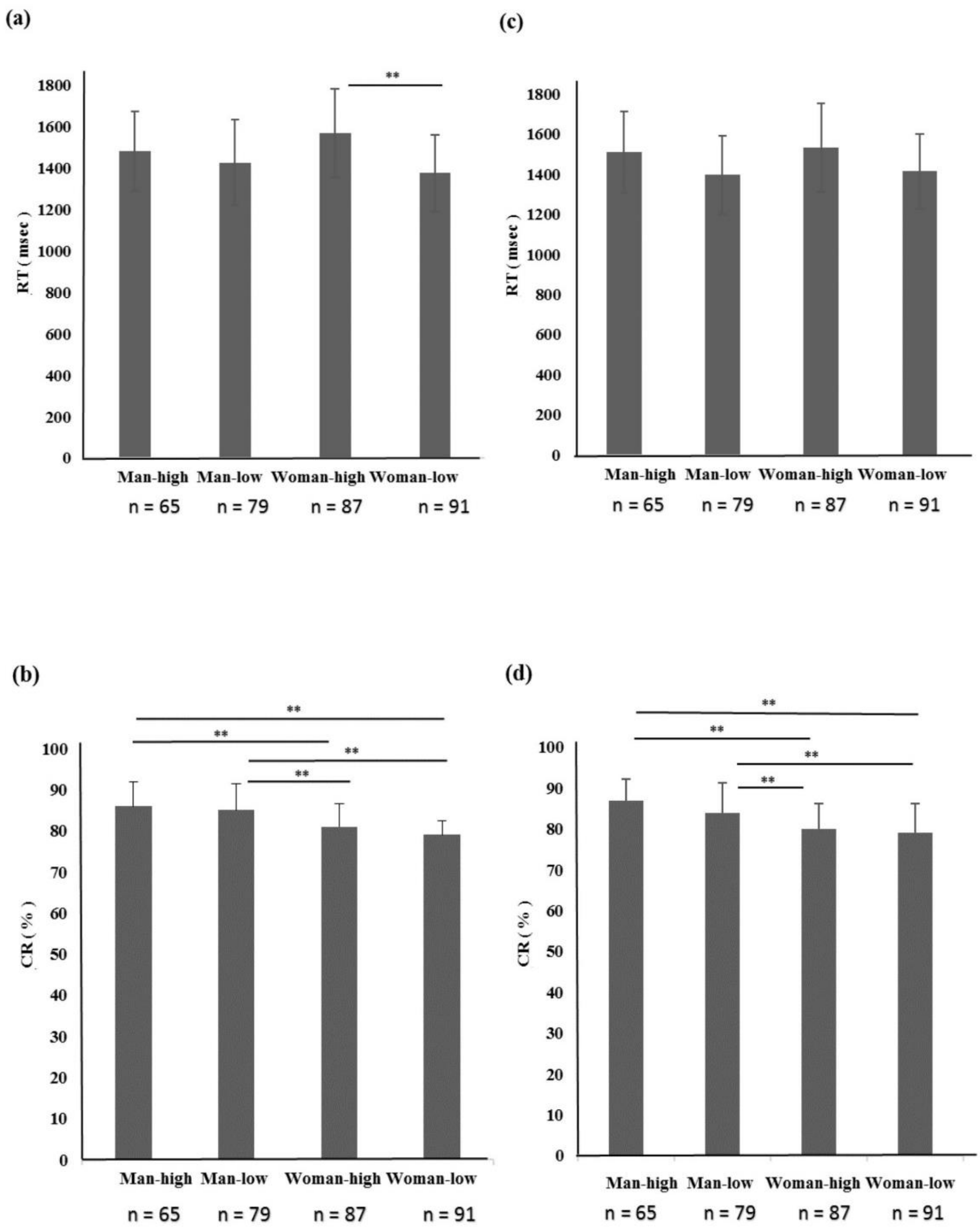


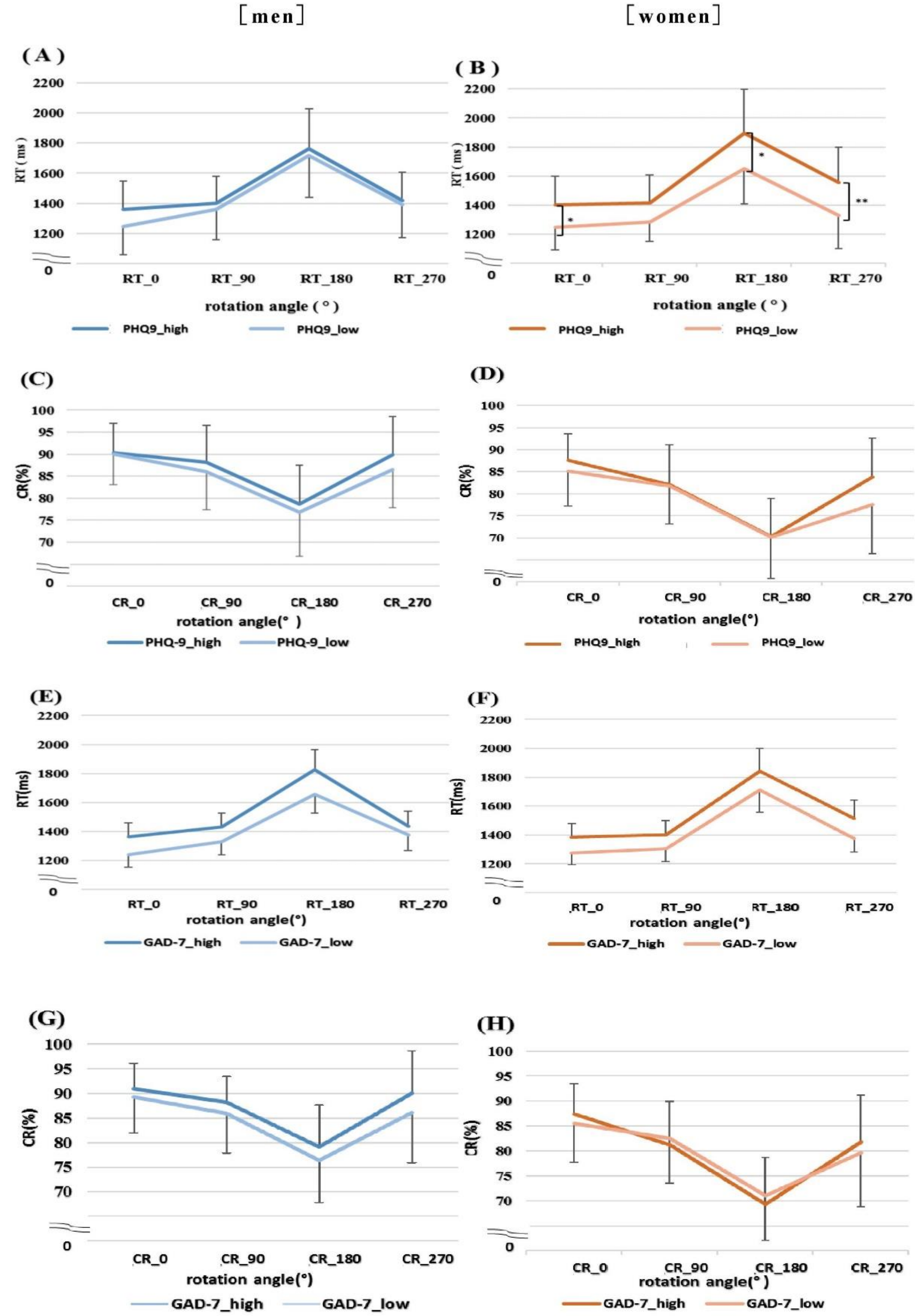
Figure3

3.4. Comparison of the effects of anxiety/depression by gender at each rotation angle

Next, using the same four groups, we compared RT and CR among the groups at each rotation angle. The results of an ANOVA revealed a significant difference in RT [$F(3,318) = 3.558$; *p*

= .015]. Next the results by gender revealed that, among women, those in the high depressive symptom group had significantly higher RT than did those in the low depressive symptom group for RT0° (*p* =.031, Hedge's g = 0.41), RT180° (*p* =.029, Hedge's g = 0.38), and RT270° (*p* =.002, Hedge's g = 0.51) (see Figure 4B); there were no significant differences between depression groups at any rotation angle for men (see Figure 4A). For CR, we observed no significant differences between the groups. However, men in the high depressive symptom group had a slightly higher CR than did those in the low depressive symptom group for CR270° (*p* =.073, *r* = 0.20) (see Figure 4C). Additionally, women in the high depressive symptom group had a slightly higher CR than did those in the low depressive symptom group for CR270° (*p* =.073, *r* = 0.31) (see Figure 4D).

In the analysis of anxiety symptoms, we found no significant differences in RT between groups at any of the rotation angles [$F(3,318) = 2.238$; $p = .084$]. Multiple comparisons, however, revealed that men with more intense anxiety symptoms had a non-significantly longer RT than did men with less intense symptoms for RT0° (*p* =.053, Hedge's g = 0.33), RT90° (*p* =.114, Hedge's g = 0.19), and RT180° (*p* =.062, Hedge's g = 0.34) (see Figure 4E). Women in the high anxiety symptom group also showed a non-significantly longer RT than did the low anxiety symptom group for RT0° (*p* =.049, Hedge's g = 0.30), RT90° (*p* =.171, Hedge's g = 0.25), RT180° (*p* =.102, Hedge's g = 0.25), and RT270° (*p* =.031, Hedge's g = 0.33) (see Figure 4F). For the CR comparison, we found no significant differences (see Figure 4G and 4H).



［men］
［women］
(A)
(B)
RT (ms)
RT_0
RT_90
RT_180
RT_270
rotation angle (°)
PHQ9_high
PHQ9_low
(C)
(D)
CR(%)
CR_0
CR_90
CR_180
CR_270
rotation angle(°)
PHQ-9_high
PHQ-9_low
(E)
(F)
RT(ms)
GAD-7_high
GAD-7_low
(G)
(H)

Figure4

4. Discussion

The results of our mental rotation task procedure were consistent with past findings (Levine, et al., 2016). Men had a significantly higher CR for the mental rotation task; however, but no gender difference in RT was found. A gender difference was reflected in CR, but not RT. We also observed no significant difference between men and women in either the PHQ-9 or GAD-7. There were no differences in the tendency for depression and anxiety in men and women; nonetheless, the ability related to mental rotation CR was higher in men than in women.

Depression and anxiety were related to RT in mental rotation only in women. PHQ-9 and RT were significantly positively correlated in women, but not in men. When comparing the high-depression group and the low-depression group, a significant difference was seen only in women, suggesting that depressive symptom induced delays in RT. On the other hand, between GAD-7 and RT, there was a weak positive correlation only in women.

There was no significant correlation between the PHQ-9 and CR, or the GAD-7 and CR in both men and women. Moreover, in both men and women, no significant difference in the CR was observed in the high- and low-group comparison in the PHQ-9 and GAD-7. Perhaps the intensity of depressive and anxiety symptoms did not relate to the CR.

Investigations of gender differences in visual processing function provides an explanation for the effects of depression and anxiety on mental rotation results. There is neurophysiological evidence to support gender differences in CR performance, with men showing superior results to those of women. When a participant tried to solve the mental rotation task, increased activation in the right inferior frontal gyrus/middle frontal gyrus, the left precuneus/posterior cingulate cortex/cuneus region, and the left middle occipital gyrus was found for men as compared to women (Semrud-Clikeman et al., 2012). The results of suggest that the men who demonstrated better CR compared to women had more functional brain regions related to mental rotation performance.

The incidence of depression and anxiety among men are about half compared to what is reported among women (Rosenfield, 1999). In this study, there were no significant gender differences in PHQ-9 and GAD-7 scores. Depression and anxiety are closely linked, and both are correlated with amygdala hyperactivity and diminished prefrontal cortex suppression (Tennen et al., 1995). In this study, the PHQ-9 and GAD-7 were significantly correlated. Further, compared to women, men had a significantly higher CR. In addition, the effects of depression and anxiety on RT were only apparent for women. We consider that these results are due to the pathology of depression and anxiety and are related neural network differences between men and women.

Mental rotation training might offset women's vulnerability to depression and anxiety. A previous study showed that emotion control strategies frequently used by men with high ability to suppress emotional expression reduced the gender difference in mental rotation accuracy (Fladung and Kiefer, 2016). Activating a wide range of brain regions by mental rotation training might reduce gender differences in CR and form a neural network that enables adaptive emotional adjustment.

In future study, we expect that depression and anxiety symptoms could be alleviated. We also used tablet devices and the newly-developed mental rotation task to collect sample data over a relatively brief period. Overall, this study is a useful addition to the literature, having simultaneously measured mental rotation performance in participants experiencing depression and anxiety in a routine, non-experimental environment.

4.1 Limitations

This study had several limitations. First, the applicability of the scales is questionable, as we examined healthy individuals. We used the PHQ-9 and GAD-7 primarily because the data collection periods were so short. However, because these scales are intended to diagnose depression and anxiety disorders, analysing healthy university led to typically low numerical values. Past researchers have noted the problems inherent in applying results derived from healthy individuals to those with disorders (Flett et al., 1997). Therefore, future research should utilize other scales when examining health individuals. Second, participants had a relatively narrow age range, as they were all university students. Therefore, the results cannot be generalized to children, middle-aged adults, or elderly adults. In addition, participants were all recruited from four departments (fashion design, education, medicine, and engineering), which means that students from the Faculty of Humanities or Faculty of Law were not included. This possibly biases our results. Third, only one type of mental performance task was conducted. Again, we employed a single task (mental rotation of the hand) because of the limited data collection time. Therefore, other issues such as letters and cubes could not be clarified. Fourth, some students might have had comorbid anxiety and depression, given that there was a high correlation between these variables. In future studies, it would be necessary to account for this complication. Finally, we did not directly examine brain functions; we can only make inferences about the underlying neurobiological results based on the findings of previous studies and action data. In addition, this was a cross-sectional study. Therefore, the associations observed are merely hypothetical; we cannot draw completely reliable inferences about causality.

5. Conclusions

In this study, we clarified gender-specific relations between mental rotation and depression/anxiety symptoms. The intensity of depressive symptoms did not affect RT in men, but it affected in women. Men showed a significantly higher CR than women, regardless of the impact of depression and anxiety on RT. The pathology of depression and anxiety was reflected in CR and RT in relation to the gender difference of brain function used in mental rotation.

Acknowledgments

We thank Dr. Atsuo Takanishi and the members of the Takanishi Laboratory, Faculty of Science and Engineering, Waseda University for their cooperation. We would like to thank Editage (www.editage.jp) for English language editing.

Funding

This work was supported by the Chiba University discretionary fund and academic contributions from Satsuki-Kai Sodegaura Satsukidai Hospital. The funding sources had no role in the design or conducting of the study; the collection, management, analysis, and interpretation of the data; or the preparation, review, approval, and decision to submit the manuscript for publication.

Contributions

All the authors have made a substantial contribution to the manuscript and have approved this submission. Chiaki Oshiyama performed the data analysis and wrote the manuscript; Chihiro Sutoh and Satoshi Okabayashi assisted with the data analysis; Hiroyuki Hamada assisted with the creation of the mental rotation task; Hiroyasu Miwa and Takuichi Nishimura developed the

application and managed the devices; Daisuke Matsuzawa, Yoshiyuki Hirano, Tetsuya Takahashi, Shin-ichi Niwa, Manabu Honda, Kazuyuki Sakatsume assisted with writing and editing the manuscript; and Eiji Shimizu conducted comprehensive supervision.

Conflict of interest

The authors declare that they have no conflicts of interest.

References

Beck, A.T., Emery, G., Greenberg, R.L., 1985. Anxiety Disorders and Phobias. Basic Books, New York.

Bennabi, D., Monnin, J., Haffen, E., Carvalho, N., Vandel, P., Pozzo, T., Papaxanthis, C., 2014. Motor imagery in unipolar major depression. Front. Behav. Neurosci. 8, 413.

Berneiser, J., Jahn, G., Grothe, M., Lotze, M., 2016. From visual to motor strategies: training in mental rotation of hands. Neuroimage. 167, 247–255.

Chen, J., Ma, W., Zhang, Y., Yang, L. Q., Zhang, Z., Wu, X., Deng, Z., 2014. Neurocognitive impairment of mental rotation in major depressive disorder: evidence from event-related brain potentials. J. Nerv. Ment. Dis. 202, 594–602.

Chen, J., Yang, L.-Q., Zhang, Z.-J., Ma, W.-T., Wu, X.Q., Zhang, X.-R., Wei, D.-H., Fu, Q.-H., Liu, G-X., Deng, Z.-H., Hua, Z., Zhang, Y., Jia, T., 2013. The association between the disruption of motor imagery and the number of depressive episodes of major anxiety. J. Affect. Disord. 150, 337–343.

Conson, M., Mazzarella, E., Frolli, A., Esposito, D., Marino, N., Trojano, L., Massagli, A., Gison, G., Aprea, N., Grossi, D., 2013. Motor imagery in Asperger syndrome: testing action simulation by the hand laterality task. PLoS One. 8, e70734.

Cooper, L.A., Shepard, R.N., 1975. Mental transformations in the identification of left and right hands. J. Exp. Psychol. Hum. Percept. Perform. 1, 48–56.

Fladung, A.K., Kiefer, M., 2016. Keep calm! Gender differences in mental rotation performance are modulated by habitual expressive suppression. Psychol. Res. 80, 985.

Flett, G.L., Vredenburg, K., Krames, L., 1997. The continuity of depression in clinical and nonclinical samples. Psychol. Bull. 121, 395–416.

Hanakawa, T., Dimyan, M.A., Hallett, M., 2008. Motor planning, imagery, and execution in the distributed motor network: a time-course study with functional MRI. Cereb. Cortex. 18, 2775–2788.

Kaltner, S., Jansen, P. 2014. Emotion and affect in mental imagery: do fear and anxiety manipulate mental rotation performance? Front. Psychol. 5, 792.

Kikuchi, M., Takahashi, T., Hirosawa, T., Oboshi, Y., Yoshikawa, E., Minabe, Y., Ouchi, Y. 2017. The lateral occipito-temporal cortex is involved in the mental manipulation of body part imagery. Front. Hum. Neurosci. 11, 181.

Kosslyn, S.M., DiGirolamo, G.J., Thompson, W.L., Alpert, N.M., 1998. Mental rotation of objects versus hands: neural mechanisms revealed by positron emission tomography. Psychophysiology. 35, 151–161.

Leahy, R.L., 2003. Cognitive Therapy Techniques: A Practitioner’s Guide. The Guilford Press, New York.

Levine, S.C., Foley, A., Lourenco, S., Ehrlich, S., Ratliff, K., 2016. Sex differences in spatial cognition: advancing the conversation. Wiley Interdiscip. Rev. Cogn. Sci. 7, 127–155.

Manikandan, S. (2011). Measures of central tendency: Median and mode. J. Pharmacol. Pharmacother. 2(3), 214–215.

Mehta, B., Schaal, S., 2002. Forward models in visuomotor control. J. Neurophysiol. 88(2), 942-53.

Okubo, M., Suzuki, H., Nicholls, M.E.R., 2014. A Japanese version of the FLADERS handedness questionnaire. Shinrigaku Kenkyu. 85, 474–481.

Parsons, L.M., 1994. Temporal and kinematic properties of motor behavior reflected in mentally simulated action. J. Exp. Psychol. Hum. Percept. Perform. 20, 709–730.

Prinz, S.M., Wehrenberg, M., 2007. The Anxious Brain: The Neurobiological Basis of Anxiety Disorders and How to Effectively Treat Them, first ed. W. W. Norton and Company, New York.

Rogers, M.A., Bradshaw, J.L., Philips, J.G., Chiu, E., Mileshkin, C., Vaddadi, K., 2002. Mental rotation in unipolar major depression. J. Clin. Exp. Neuropsychol. 24, 101–106.

Rosenfield, S., 1999. Gender and mental health: do female have more psychopathology, men more, or both the same (and why), in: Horwitz, A.V., Schneid, T.L. (Eds.), A Handbook for the Study of Mental Health: Social Contexts, Theories, and Systems. Cambridge University Press, New York, pp. 348–360.

Semrud-Clikeman, M., Fine, J.G., Bledsoe, J., Zhu, D.C., 2012. Gender differences in brain activation on a mental rotation task. Int. J. Neurosci. 122, 590–597.

Shepard, R.N., Metzler, J., 1971. Mental rotation of three-dimensional objects. Science. 171, 701–703.

Spitzer, R.L., Kroenke, K., Williams, J.B., 1999. Validation and utility of a self-report version of PRIMEMD: the PHQ primary care study. JAMA. 282, 1737–1744.

Spitzer, R.L., Kroenke, K., Williams, J.B., Lowe, B., 2006. A brief measure for assessing generalized anxiety disorder: the GAD-7. Arch. Intern. Med. 166, 1092–1097.

Sutoh, C., Matsuzawa, D., Hirano, Y., Yamada, M., Nagaoka, S., Chakraborty, S., Ishii, D., Matsuda, S., Tomizawa, H., Ito, H., Tsuji, H., Obata, T., Shimizu, E., 2015. Transient contribution of left posterior parietal cortex to cognitive restructuring. Sci. Rep. 5, 9199.

Taylor, T.J.V., Clark, L., Cannon, D.M., Erickson, K., Drevets, W.C., Sahakian, B.J., 2007. Distinct profiles of neurocognitive function in unmedicated unipolar anxiety and bipolar II depression. Biol. Psychiatry. 62, 917–924.

Tennen, H., Hall, J.A., Affleck, G., 1995. Anxiety research methodologies in the Journal of Personality and Social Psychology: a review and critique. J. Pers. Soc. Psychol. 68, 870–884.

Thoresen, J.C., Francelet, R., Coltekin, A, Richter, K. F., Fabrikant, S. I., Sandi, C., 2016. Not all anxious individuals get lost: Trait anxiety and mental rotation ability interact to explain performance in map-based route learning in men. Neurobiol. Learn. Mem. 132, 1–8.

Tomasino, B., Gremese, M., 2016. Effects of stimulus type and strategy on mental rotation network: an activation likelihood estimation meta-analysis. Front. Hum. Neurosci. 9, 693.

Thompson, K.L., Kosslyn, S.M., 2000. Neural systems activated during visual mental imagery: A review and meta-analysis. In A. w. Toga and J.C.Mazziotta (Eds.), Brain mapping: the systems. 535-560. San Diego, CA: Academic press.

Table legend

Table 1 Correlational Analysis Between Each Variable and Gender Differences

Figure Legends

Fig. 1 Mental rotation hand task programmed on the tablet device

Fig. 2 Mental rotation performance comparison and the degree of depression and anxiety. *A,* Average of correct answer rate / Average for men and women and comparison between men and women. *B,* Stastics and gender Comparison PHQ-9 GAD-7. *C,* Average of RT / Average for men and women and comparison between men and women.

Note. RT = response time, CR = correct answer rate, PHQ-9 = Patient Health Questionnaire, GAD-7 = Generalized Anxiety Disorder. Error bars indicate the standard deviation. ***$p < .001$, **$p < .01$

Fig. 3 Comparison of the effects of anxiety and depression by gender. *a*, Differences by gender and depressive symptom intensity in RT. *b*, Differences by gender and depressive symptom intensity in CR. *c*, Differences by gender and anxiety symptom intensity in RT. *d*, Differences by gender and anxiety symptom intensity in CR.

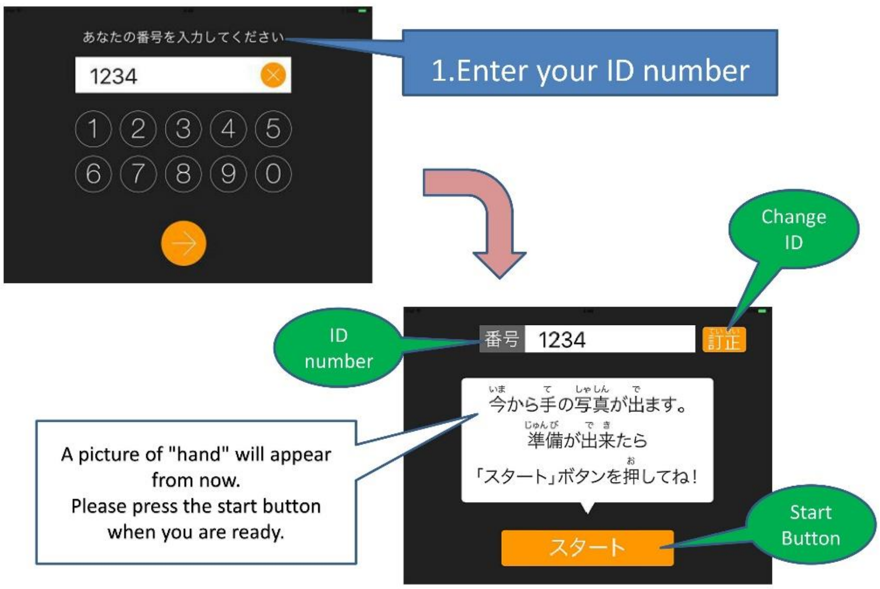
Note. RT = response time, CR = correct answer rate, PHQ-9 = Patient Health Questionnaire, GAD-7 = Generalized Anxiety Disorder. Error bars indicate the standard deviation. ***$p < .001$, **$p < .01$.

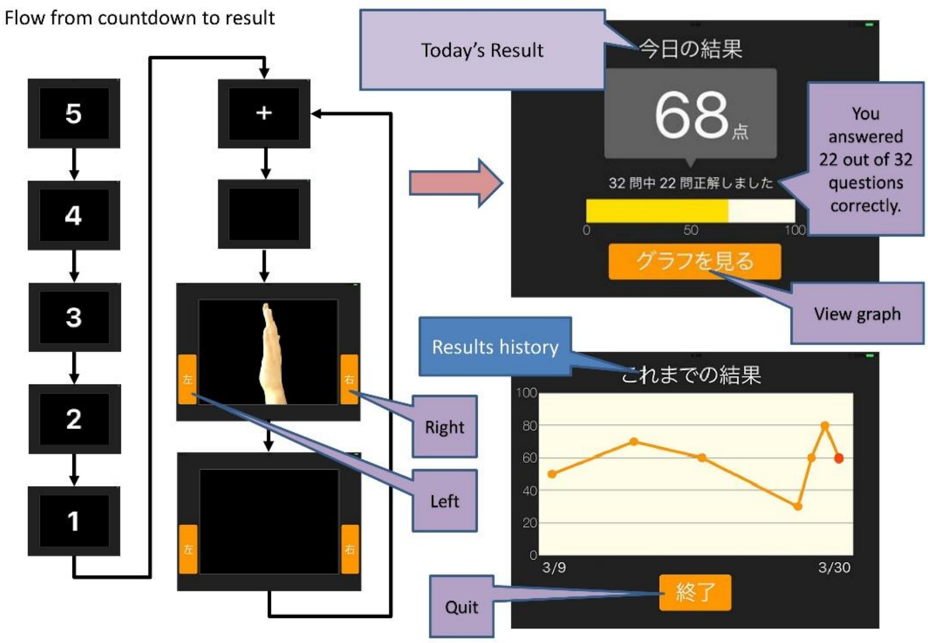
Fig. 4 Gender differences in RT and CR for the PHQ-9 and GAD-7 groups at each rotation angle. *A*, RT by depressive symptom intensity in men. *B*, RT by depressive symptom intensity in women. *C*, CR by depressive symptom intensity in men. *D*, CR by depressive symptom intensity in women. *E*, RT by anxiety symptom intensity in men. *F*, RT by anxiety symptom intensity in women. *G*, CR by anxiety symptom intensity in men. *H*, CR by anxiety symptom intensity in women.

Note. RT = response time, CR = correct answer Rate, PHQ-9 = Patient Health Questionnaire, GAD-7 = Generalized Anxiety Disorder 7-item scale. Error bars indicate the standard deviation.

***$p < .001$, **$p < .01$.

Supplementary file 1





Supplementary file 2

Descriptive Statistics for Each Variable and Gender Differences

	Total (n = 322)				Male (n = 144)				Female (n = 178)				Male × Female		Effect Size	
	M	*SD*	95% CIL	95% CIU	*M*	*SD*	95% CIL	95% CIU	*M*	*SD*	95% CIL	95% CIU				
RT (ms)	1460.78	406.20	1416.7	1505.55	1451.69	399.94	1385.808	1517.5662	1468.76	410.32	1408.068	1529.4537	*F* = 0.141	*p*=.708	*n.s.*	*g* = 0.03
RT0° (ms)	1312.58	369.96	1272.02	1353.14	1298.20	377.16	1236.0774	1360.3316	1324.21	364.69	1270.2672	1378.1548	*F* = 0.393	*p*=.531	*n.s.*	*g* = -0.05
RT90° (ms)	1362.16	381.84	1320.3	1404.03	1379.23	383.39	1316.0797	1442.3866	1348.35	381.10	1291.9824	1404.7255	*F* = 0.520	p=.471	*n.s.*	g = 0.05
RT180° (ms)	1756.08	588.09	1691.61	1820.56	1738.01	546.53	1647.9847	1828.0391	1770.70	620.82	1678.871	1862.5311	*F* = 0.245	*p*=.621	*n.s.*	*g* = -0.03
RT270° (ms)	1423.35	424.92	1376.76	1469.93	1404.15	412.63	1336.1843	1472.123	1438.87	435.16	1374.5052	1503.2392	*F* = 0.531	*p*=.467	*n.s.*	*g* = -0.06
CR (%)	82.22	13.39	80.7381	83.6835	85.46	12.81	83.35006	87.57008	79.58	13.38	77.60257	81.56175	*U* = 19.12	*p*= .0000089	***	*r* = 0.32
CR0° (%)	88.03	13.43	86.4861	89.5663	90.12	13.66	87.872862	92.374053	86.33	14.16	84.234754	88.424425	χ^2 = 8.24	*p*=.004	**	*r* = 0.19
CR90° (%)	84.21	14.05	82.2778	86.1339	87.00	17.14	84.180764	89.827172	81.94	17.66	79.329519	84.554911	χ^2 = 8.79	*p*=.003	**	*r* = 0.21
CR180° (%)	73.53	17.59	71.4689	75.5981	77.62	18.95	74.501841	80.745073	70.22	18.12	67.544425	72.905013	χ^2 = 15.22	*p* =.000095	***	*r* = 0.29
CR270° (%)	83.90	18.83	81.7723	86.0183	88.00	17.28	85.148925	90.843138	80.58	20.34	77.568494	83.587204	χ^2 = 15.06	*p*=.000104	***	*r* = 0.28
PHQ-9	7.01	4.58	6.51	7.51	6.89	4.61	6.13	7.65	7.11	4.57	6.44	7.79	*F* = 0.189	*p*=.664	*n.s.*	*g* = -0.07
GAD-7	4.30	4.13	3.85	4.75	4.29	4.09	3.62	4.97	4.30	4.17	3.69	4.92	*F* = 0.001	*p*=.980	*n.s.*	*g* = -0.004

Note. M = mean, SD = standard deviation, RT = response time, CR = mental rotation correct answer rate, n.s. = not significant, PHQ-9 = 9-item Patient Health Questionnaire, GAD-7 = Generalized Anxiety Disorder 7-item scale, CIL = confidence interval lower limit, CIU = confidence interval upper limit

$^*p < .05$, $^{**}p < .01$, $^{***}p < .001$.