ACTA ODONTOLOGICA SCANDINAVICA
2019, VOL. 77, NO. 7, 525–533
https://doi.org/10.1080/00016357.2019.1610190

Taylor & Francis
Taylor & Francis Group

ORIGINAL ARTICLE

Association between sensory processing and dental fear among female undergraduates in Japan

Mika Ogawa[a], Nozomu Harano[a], Kentaro Ono[b], Yukiyo Shigeyama-Tada[a], Tomoko Hamasaki[c] and Seiji Watanabe[a]

[a]Division of Dental Anesthesiology, Kyushu Dental University, Fukuoka, Japan; [b]Division of Physiology, Kyushu Dental University, Fukuoka, Japan; [c]Department of Nutrition, Kyushu Women's University, Fukuoka, Japan

ABSTRACT
Objectives: The aim of cross-sectional study was to investigate the association between sensory processing patterns and dental fear among female undergraduates.
Material and methods: Three hundred and ten female university students were included in the present study. Dental fear and sensory processing patterns were measured using the Dental Fear Survey and Adolescent/Adult Sensory Profile with other possible confounders, respectively. Sensory processing patterns were categorized into sensory sensitivity, sensory avoidance, low registration and sensation seeking. We conducted structural equation modelling based on the hypothesis that sensory processing directly affects dental fear, including the confounding role of negative experiences with dentistry, autistic traits and the mediating role of trait anxiety.
Results: Based on our proposed model, sensory processing patterns, excluding sensation seeking and negative experiences significantly contributed to dental fear ($\beta = 0.33$, $p < .001$ and $\beta = 0.32$, $p < .001$, respectively) and autistic traits and trait anxiety did not significantly contribute to dental fear.
Conclusions: Extreme sensory processing patterns seem to be associated with a high level of dental fear; thus, the difference in sensory processing might play an important role in the aetiology of dental fear.

ARTICLE HISTORY
Received 29 August 2018
Revised 23 March 2019
Accepted 15 April 2019

KEYWORDS
Dental fear; sensory processing; structural equation modelling

Introduction

Avoiding dental treatment because of fear [1] results in poor dental health [2] and reduced quality of life [3,4]. Approximately, 40% of Japanese [5,6] patients have reported high levels of dental fear. Epidemiological studies from other countries have revealed that approximately 15%–40% of communities have experienced high levels of dental fear [7–9]. Dental fear is a complex phenomenon with exogenous and endogenous components [10]. The most important exogenous component of dental fear is a traumatic or painful dental experience in the past [11]. Negative dental experiences of family or friends and/or social media can influence dental fear [12]. Moreover, personal factors, such as anxiety, panic disorders and depression representing endogenous components, contribute to dental fear development [13–15]. In addition, sex differences in dental fear have been reported; women tend to be more fearful than men [16,17].

The aetiology of dental fear has been previously explained using classical conditioning theory through negative dental experiences and operant conditioning [18,19]. First, a strengthened association is made between dental treatment-related stimuli and negative dental experiences, such as pain or lack of control. Then, the drill sound and the peculiar smell of a dental clinic (conditioned stimuli) provoke fear in patients (classical conditioning) [18]. This conditioned fear makes a patient avoid dental treatment, and avoidance perpetuates the learned association between conditioned stimuli and negative physical and emotional states (operant conditioning). Avoidance results in more dental problems and more painful dental treatment experiences that further reinforce the conditioned dental fear, which is a vicious cycle [20].

It is noteworthy that biological and genetic factors play an important role in the development and maintenance of dental fear [18,19]. Genetic differences make some patients develop fear more easily than others through the learning-, cognitive-, personality- and/or pain-based aetiological mechanisms. Some fearful patients have catastrophizing or misappraisal thinking (cognitive distortions) [18]. A genetic variation, which is related to the fear of pain, was found to be related to dental fear [21,22]. This vulnerability seems to be the predisposition to dental fear.

Dental treatment-related stimuli provoke dental fear via classical conditioning [18], it may also provoke dental fear through biological and genetic mechanisms. Patients with dental fear can be highly sensitive to dental treatment (e.g. the sight of a needle, sensation of the drill, taste of medications, and bright dental light) even if it is a painless procedure. It is

CONTACT Nozomu Harano harano@kyu-dent.ac.jp Division of Dental Anesthesiology, Kyushu Dental University, Kitakyushu, Fukuoka, Japan. Address: 2-6-1, Manazuru, Kokura-kita, Kitakyushu, Fukuoka 803-8580 Japan

suggested that dental fear is associated with lower distress tolerance to aversive or uncomfortable emotional states [23], and in turn, lower distress tolerance might be associated with higher sensitivity to sensation and/or emotion. We postulate that patients with hypersensitivity to sensation can have more to negative responses to dental procedures. Moreover, fear conditioning might happen more easily for individuals with an extreme sensory processing pattern who have negative experiences, resulting in the subsequent development/maintenance of fear.

Sensory processing is defined as 'the ability to register and modulate sensory information and organize sensory input to respond to situational demands' [24]. Genetic and environmental factors contribute to sensory processing [25,26]. Sensory processing patterns refer to observed behavioural responses to external stimulation after modulating sensory information [25,26]. Each person has different sensory processing patterns and strengths that are considered to be part of their individual characteristics, and extreme sensory processing patterns interfere with daily life [26]. Although extreme sensory processing patterns are present in approximately 15% of the general population [27,28], they are present in >90% of adults with autism spectrum disorder (ASD) [29]. Sensory processing interventions for children with disabilities are commonly used in the field of occupational therapy [30,31].

Some conceptual models of sensory processing differences have been developed [25,32,33]. Dunn developed a sensory processing model from the perspective of neuroscience and behavioural science by observing young children's behaviour. The model was constructed considering an individual's neurological threshold continuum (high to low) and behavioural response continuum (active to passive) [25]. In this model, people with a low neurological threshold to external stimulations are classified with sensory sensitivity as a passive response or sensory avoidance as an active response. Furthermore, those with a high neurological threshold are classified with low registration as a passive response and sensation seeking as an active response [25]. Each individual can have one or more sensory processing patterns, and extremely high or low level of sensory processing is untypical [34].

Because sensory processing is genetically based [26] and untypical sensory processing results in maladaptive emotional and behavioural responses to sensory input [33], several psychological correlations have been reported. A cross-sectional study among healthy adults revealed that sensory sensitivity, sensory avoiding and low registration patterns were associated with pain catastrophizing [35]. Another cross-sectional study concluded that individuals with extreme sensory processing patterns could have a high level of general anxiety [36]. Moreover, extreme sensory processing patterns were associated with major affective disorders, including depression, impulsivity, alexithymia, and hopelessness [37]. Although sensory processing is genetically based, it can be influenced by environmental factors [25,26] and correlated with traumatic childhood experiences in patients with an affective disorder [38]. Furthermore, individuals with post-traumatic stress disorder (PTSD) demonstrated a higher degree of extreme sensory processing pattern than individuals without PTSD [39].

An association has recently been established between sensory hypersensitivity based on Dunn's model and uncooperative behaviour during routine oral care among children with ASD [40]. In addition, a difference in sensory processing patterns has influenced children with typical development in stimulus-rich environments, such as classrooms [41]. However, to the best of our knowledge, it is not known whether a difference in sensory processing patterns is associated with dental fear in healthy adults.

The aim of this study was to investigate whether sensory processing patterns to non-aversive stimuli are associated with dental fear among young female patients while controlling other risk factors of dental fear using structural equation modelling (SEM).

Material and methods

Design and study population

All of the 351 healthy female students from the Department of Nutrition in the Women's University, Kitakyushu, Japan, were targeted in the study. This cross-sectional study was approved by the Ethics Committee of Kyusyu Dental University (No. 17-11) and was performed in April 2017. The participants were recruited at the start of their class. Inclusion criteria were attendance to the class, and exclusion criteria were absence from the class. A self-administered questionnaire was filled out by each participant during the class after written consent was obtained. Seventeen students were absent from the class, and 334 participants completed the questionnaire.

Measures

Dental fear survey

The Dental Fear Estimation by Dental Fear Survey (DFS) [42], a 20-item self-report measure, is commonly applied to measure behavioural and physiological responses when evaluating anxiety or fear due to dental care. Using a 5-point Likert-type scale, a higher score indicates greater dental fear. The questionnaire comprises three parts: avoidance, physiological arousal, and fear of specific situations.

Sensory processing pattern by adolescent/adult sensory profile

Based on Dunn's sensory processing model, the Adolescent/Adult Sensory Profile (AASP) was used to assess sensory processing patterns [34]. The 60-item questionnaire measured sensory responses to stimuli encountered in daily life. Each item was scored on a 5-point Likert scale (ranging from 1 = almost never to 5 = almost always). The 60 items were equally sorted into four quadrants: sensory sensitivity, sensory avoidance, low registration and sensation seeking. A higher score indicates more disturbed levels of sensory processing. The Japanese version of AASP has high reliability and validity. Cronbach α scores for the Japanese version of AASP were 0.76 (sensory sensitivity), 0.80 (sensory avoidance), 0.80

(low registration), and 0.75 (sensation seeking) [43]. Validity was shown using Z-test between adults without disabilities and adults with ASD and without disabilities [$z = 1.99$, $p < .05$, d = 0.30 (sensory sensitivity); $z = 1.39$, $p > .05$, d = 0.21 (sensory avoidance); $z = 2.91$, $p < .01$, d = 0.43 (low registration); and $z = 3.61$, $p < .001$, d = 0.54 (sensory sensitivity) [43]. The cut-off points for high level of sensory processing patterns (out of 1 standard deviation samples among individuals without disabilities and aged 18–34 years) are 43 (sensory sensitivity), 42 (sensory avoidance), 39 (low registration), and 48 (sensation seeking) [43].

Negative experiences with dentistry

Negative experiences play an important role in the aetiology of dental fear via conditioning. Not only direct negative dental experiences (i.e. painful dental treatment) but also indirect negative dental experiences from friends, family members and social media (social learning) [12,18] influence dental fear development. We asked the following six questions related to negative dental and medical experiences that could be risk factors of dental fear: 'Have you ever received dental treatment?'; 'Have you ever experienced unbearable pain from dental treatment?'; 'Have you ever had dental treatment by a scary dentist?'; 'Have you ever experienced unbearable pain from medical treatment?'; 'Does your family avoid dental treatment?'; and 'Have you ever seen a scary dentist in the media?' All six questions were answered with 'Yes' or 'No.'

State–trait anxiety inventory

The State–Trait Anxiety Inventory (STAI) [44] measures the severity of trait and state anxiety. Trait anxiety is a relatively stable behavioural disposition to respond anxiously, whereas state anxiety is a transitory emotional state.

Autism–spectrum quotient

The 50-item Autism–Spectrum Quotient (AQ) [45] is a self-administered instrument for measuring the degree of autistic traits. The questionnaire comprises four parts: social skill, attention switching, local details and communication and imagination.

Demographic questionnaire

The participants' age and sex were recorded. All questionnaires were written in Japanese. The Japanese versions of DFS [46], AASP [43], STAI [47] and AQ [48] (Copyright [c] Sankyobo) have been proven by other studies to be highly reliable and valid for each purpose.

Statistics

We conducted descriptive statistics. Preliminary correlation analysis using Spearman correlation coefficient was used to explore associations among dental fear, sensory processing, and other continuous variables and to screen for multicollinearity. Variance inflation factor (VIF) was calculated to check multicollinearity, with a VIF of <5 suggested for detecting multicollinearity [49].

The SEM method is a comprehensive statistical approach for testing the hypotheses regarding the relationship between observed and latent variables and is commonly used in the field of behavioral sciences [50]. SEM can be simultaneously performed by multiple regression, correlation and factor analyses [50]. SEM was performed using weighted least squares parameter estimates (WLSMV). Our data included six dichotomous variables; thus, we used WLSMV, which is a robust estimator and provides one of the best choices for modelling categorical data [51]. Sensory processing was hypothesized to directly affect dental fear; negative experiences with dentistry and autistic traits confounded the relation, and trait anxiety mediated the relation. A modified model was used to remove non-significant variables from a hypothetical model. Model fitting resulted in global fit indices. Preliminary correlation analysis was conducted using IBM SPSS Statistics software version 24 (IBM SPSS, Armonk, NY, USA) and SEM was conducted Mplus version 8 (Muthen & Muthen, Los Angeles, CA). All tests were conducted at a significance level of 0.05.

Results

Of the 334 participating students, 24 were excluded because of incomplete data in their questionnaires. The response rate to the questionnaire was 92.8%.

Study group characteristics

Age, sex, dental fear, sensory processing, and other variables that contribute to dental fear are presented in Table 1. In total, 9% of the respondents showed high levels of dental fear, and approximately, 20% showed high levels of sensory processing.

Preliminary correlational analysis

As shown in Table 2, sensory sensitivity, sensory avoidance, and low registration exhibited weak-to-moderate positive correlations with dental fear ($r = 0.37$, $p < .01$; $r = 0.27$, $p < .01$; and $r = 0.24$, $p < .01$, respectively). Sensation seeking was not correlated with dental fear. Positive relationships existed among sensory sensitivity, sensory avoidance, and low registration. Sensation seeking correlated to some extent with other sensory processing patterns. Correlations between other variables are shown in Appendix 1.

SEM

Figure 1 illustrates the hypothesized and modified models. The goodness-of-fit test in the modified model was better than that in the hypothesized model (Table 3). The value of chi-square was not significant, which indicated that observed data did not significantly differ from those in the hypothetical model [52]. The comparative fit index (CFI) and Tucker–Lewis index (TLI) >0.90 indicated a well-fitting model [52]. The model with the standardized root mean square residual (SRMR) >0.8 [53] and the root mean square error of approximation (RMSEA) <0.05 indicated a well-fitting model [50]. CFI, TLI, SRMR and RMSEA values for the modified model indicated better model fitting. State anxiety was removed from the hypothetical model because state anxiety and trait anxiety had a high correlation and caused occurrence of an improper solution (factor loading > 1) in factor analysis. Dental attendance was also removed because it caused analysis iteration. Sensation seeking was removed from the modified model because of low factor loading (Appendix 2).

Among female students, this model demonstrated that (1) sensory processing patterns, except sensation seeking, and negative experiences were significantly related with high dental fear (($\beta = 0.38$, $p < .001$ and $\beta = 0.36$, $p < .001$, respectively); (2) Trait anxiety, autism–spectrum quotient, and age were not significantly related with high dental fear; (3) Negative experiences and autistic traits were significantly contributed to sensory processing ($\beta = 0.32$, $p < .001$ and $\beta = 0.46$, $p < .001$, respectively); and (4) sensory processing significantly contributed to trait anxiety ($\beta = 0.33$, $p < .001$) (Figure 1).

Table 1. Descriptive data for study variables.

Variable	N	Mean or %	Standard Deviation
Sociodemographics			
Age	310	19.7	2.3
Sex: Female	310	100%	–
DFS	310	36.5	15.6
High (≥60)	28	9.0%	–
Low (<60)	282	91.0%	–
Sensory processing			
Sensory sensitivity	310	36.3	8.3
High (≥43)	54	17.4%	–
Low (<43)	256	82.6%	–
Sensory avoidance	310	35.0	8.5
High (≥42)	61	19.7%	–
Low (<42)	249	80.3%	–
Low registration	310	33.8	7.6
High (≥39)	69	22.3%	–
Low (<39)	241	77.7%	–
Sensation seeking	310	40.7	8.3
High (≥48)	61	19.7%	–
Low (<48)	249	80.3%	–
Negative experiences			
Dental attendance			
Yes	297	95.8%	–
No	13	4.2%	–
Painful dental treatment			
Yes	55	17.7%	–
No	255	82.3%	–
Painful medical treatment			
Yes	62	20.0%	–
No	248	80.0%	–
Dental treatment by scary dentist			–
Yes	11	3.5%	–
No	299	96.5%	–
Family's dental fear			–
Yes	70	22.6%	–
No	240	77.4%	–
Seeing scary dentist in the media			
Yes	21	6.8%	–
No	289	93.2%	–
Personal factors			
STAI (State)	310	42.3	7.8
High (≥55)	13	4.2%	–
Medium + Low (<55)	297	95.8%	–
STAI (Trait)	310	48.2	9.0
High (≥55)	61	19.7%	–
Medium + Low (<55)	249	80.3%	–
AQ	310	21.4	6.1
High (≥33)	4	1.3%	–
Low (<33)	306	98.7%	–

DFS: Dental Fear Survey; STAI: State–Trait Anxiety Inventory; AQ: Autism–Spectrum Quotient.

Discussion

To the best of our knowledge, this is a novel identification of an association between certain sensory processing patterns and dental fear using SEM.

We found that certain sensory processing patterns were associated with dental fear among female students. Very little literature is available about sensory processing in the dental fields. Our findings were consistent with those of a previous study in which visual/auditory sensitivity was correlated with uncooperative behavior among children with ASD; furthermore, tactile sensitivity and movement sensitivity were correlated with uncooperative behaviour among typically developed children [40]. Uncooperative behaviour is sometimes referred to as a dental behaviour management problem; it can be a consequence of dental fear, but also other individual characteristics [54,55]. A sensory-adapted environment using dim lighting or relaxing music reduces uncooperative behaviour among children with ASD [56]. Our findings and those of previous studies suggest that hypersensitivity to sensation might be associated with uncooperative behaviour via dental fear and/or personal characteristics. In addition, autistic traits were not associated with dental fear in the present study. Sensory processing may be associated with dental fear without confounding autism traits in adults of typical development.

Difference in sensory processing may have a role in the development and maintenance of dental fear as a biological and genetic factor. Genetic contributions to the development/maintenance of dental fear are reported. Dental fear is shown to be heritable and related to the fear of pain [21,22,57]. Variation in the melanocortin-1 receptor gene, which is associated with red hair colour and lower sensitivity to local anaesthesia, has been identified as a predictor of

Table 2. Correlations between variables using Spearman's ρ ($N = 310$).

	DFS	Sensory Sensitivity	Sensory Avoidance	Low Registration
DFS				
Sensory sensitivity	0.371**			
Sensory avoidance	0.273**	0.618**		
Low registration	0.238**	0.506**	0.438**	
Sensation seeking	NS	0.119*	NS	0.160**

**$p < .01$; *$p < .05$.
DFS: Dental Fear Survey.
NS: Non-significant.

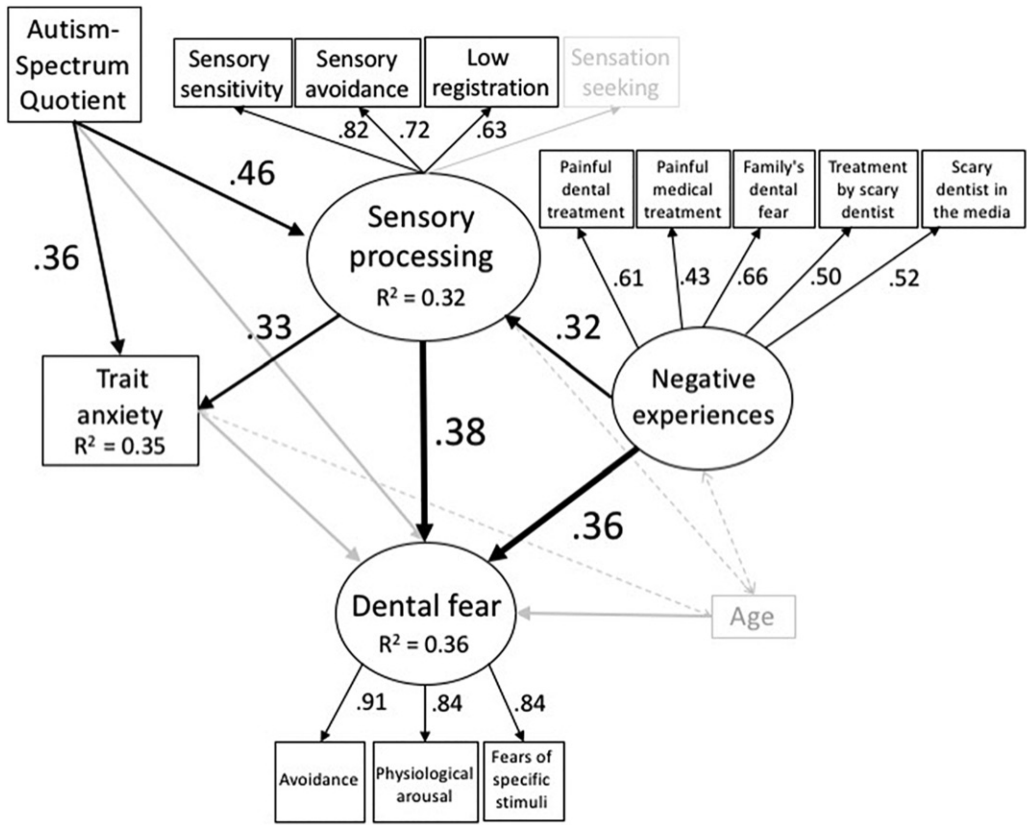

Figure 1. A hypothetical and modified model of the association between dental fear and sensory processing, including other related factors. Circles indicate a latent variable, and squares indicate an observed variable. Arrows from a latent variable (independent variable) to a latent variable (dependent variable) indicate a multiple regression analysis, arrows from a latent variable to an observed variable indicate factor analysis, and 2-way arrows indicate a correlation. The gray line in the hypothesis was removed after confirming model fitting. The modified model is shown using black lines.

Table 3. Goodness-of-fit index of the hypothesized and modified models.

Models	Chi-square	df	*p*-value	CFI	TLI	SRMR	RMSEA (95% CI)
Hypothesized	874	105	$<.001$	0.875	0.837	0.138	0.062 (0.050–0.074)
Modified	64.6	60	.32	0.994	0.992	0.082	0.016 (0.000–0.039)

CFI: Comparative Fit Index; TLI: Tucker–Lewis Index; SRMR: Standardized Root Mean Square Residual; RMSEA: Root Mean Square Error of Approximation; CI: Confidence Interval.

dental fear [57]. Because sensory processing is based on genetic factors [26], it is conjectured to play a role in genetic and biological predispositions to dental fear and leads to fear conditioning and/or cognitive and personality vulnerability (Figure 2).

Our proposed model demonstrated that sensory sensitivity, sensory avoidance, and low registration were related to dental fear. A previous study reported that these three observed sensory processing patterns were related to pain catastrophizing [35]. Catastrophizing is defined as an increasing negative interpretation of pain [58]. Catastrophic thinking increases fear in patients with chronic pain [59] and acts as a moderator of dental fear [60]. Extreme responses in the three sensory processing patterns may increase dental fear by catastrophic thinking about dental treatment as especially painful and uncomfortable, perhaps irrationally so (i.e. cognitive distortions).

Furthermore, sensory processing might form the ground for dental fear development, which seems to predispose the easy development of dental fear with negative dental experiences via conditioning. Actually, our model showed that negative experiences with dentistry confounded the relation between sensory processing and dental fear. Because individuals with sensory sensitivity and sensory avoidance patterns have a low neurological threshold to external stimuli [25], they might be conditioned by less aversive stimuli than patients with normal sensory pattern. Furthermore, it has been reported that low distress tolerance plays a role in dental fear compounding anxiety sensitivity [23]. Distress tolerance refers to an individual's ability to tolerate negative, aversive, or uncomfortable states [61], and anxiety sensitivity can be defined as the 'fear of anxiety' [62]. Individuals with sensory sensitivity and/or avoiding pattern might be more sensitive to the feelings of anxiety, more easily find this feeling harmful and avoid aversive situations than individuals with normal sensory pattern. These tendencies seem to predispose people to dental fear and to the susceptibility of fear conditioning.

Low registration was also positively correlated with dental fear. Lower ability to register sensory input is associated with depression and alexithymia, which characterizes difficulties in identifying and expressing feelings to others [37]. Depression and alexithymia are related to dental fear as personal factors [63,64]. Low registration might be related to high dental fear

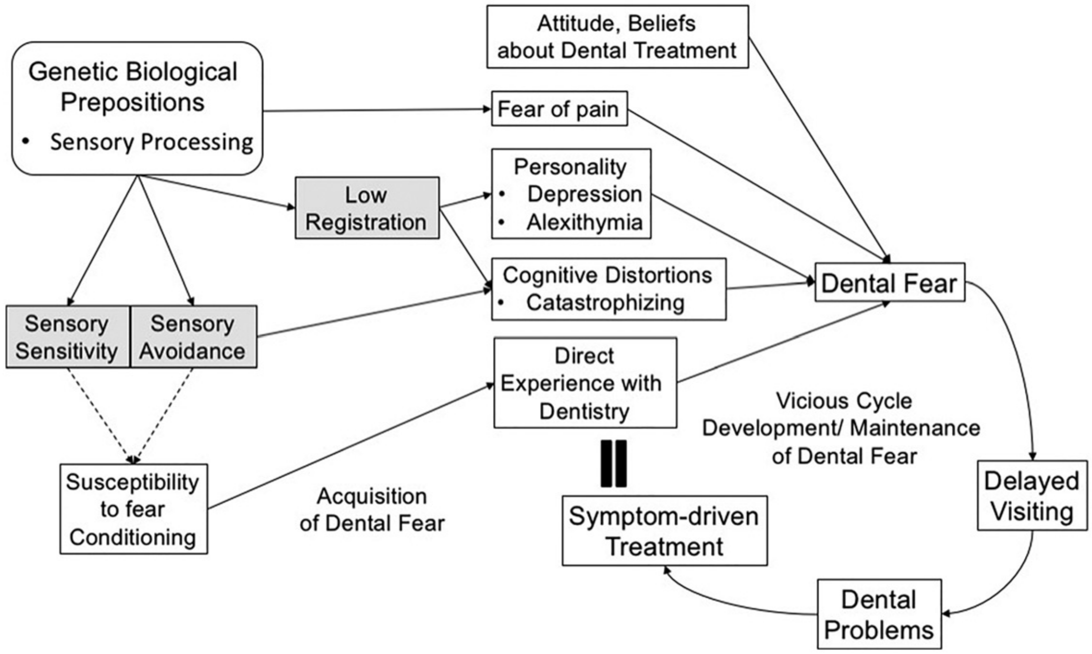

Figure 2. A potential aetiological mechanism of sensory processing in the established models of dental fear/avoidance [18,20]. The dotted lines indicate an association, which had not been investigated but is conjectured.

via personality vulnerability to dental fear. Our findings and those of other previous reports [35,36] have revealed that low registration is positively correlated with sensory sensitivity and sensory avoidance. According to Dunn's model, low registration and sensory sensitivity involve opposite neurological thresholds and therefore, logically should not occur in the same individual, but clinically, they can occur in the same individual. A previous report [36] discussed whether low registration was a defense against an oversensitive processing system. Another report mentioned that individuals with extremely low registration failed to detect sensations, suddenly experienced distress, and might not recognize the warnings of imminent stressors [35]. Furthermore, another previous study which has explored the association between sensory processing patterns and individual's personality suggested that individuals with extremely low registration showed psychological and social difficulties similar to that observed in individuals with a low neurological threshold [65]. The authors suggested that some individuals with abnormal sensory processing do not easily regulate sensory processing. Moreover, our findings indicated that one latent variable, namely sensory processing, was referred from sensory sensitivity, sensory avoidance and low registration pattern. These three patterns are distinctly observed patterns; however, a part of their components might be rooted in the same sensory processing difficulties (Figure 2).

Sensation seeking was the only sensory processing pattern that was not significantly correlated with dental fear, pain catastrophizing [35] or trait anxiety [36]. Sensation seekers tend to manage conditions related to sensory stimulations and emotions [66], searching for and enjoying sensory experiences [26]. Sensation seeking may hardly be related to dental fear development.

Figure 2 shows a potential etiological mechanism of sensory processing in the established models of dental fear/avoidance [18,20]. Difference in sensory processing could be aetiologically important in the acquisition of fear via the susceptibility to fear conditioning and cognitive vulnerability. After the acquisition of fear, sensory processing might influence maintenance or the development of dental fear as a part of the 'Vicious Cycle' [20]. However, the theory remains a matter of speculation because only 9% of our sample had high dental fear. Future studies are needed.

In contrast to the results of previous studies, our study showed that trait anxiety was not significantly related to a high level of dental fear. A longitudinal study reported that the onset of dental anxiety in early adulthood is influenced by psychological disorders [14]. Several cross-sectional studies have reported a relationship between dental fear and depressive and/or anxiety disorders [13,15,67]. There are three potential reasons that trait anxiety was not significantly related to a high level of dental fear in this study. Firstly, the participants in the current study were students, and only 9% of them showed high level of dental fear; thus, the association between dental fear and trait anxiety could be masked, such as in the healthy worker effect [68]. Secondly, because the study samples were restricted and homogenous, the association might have been undetected. Finally, sensory processing appeared to be a confounding factor between dental fear and trait anxiety. No previous studies have investigated the association between dental fear, trait anxiety, and sensory processing; therefore, future multivariate analysis studies are needed.

As all of our participants were female students, it was not possible to comprehensively evaluate whether social factors, including age, were related to dental fear in our model [69,70].

This study had some limitations. Firstly, psychological variables already known to be related to dental fear (e.g. cognitive distortions, fear of pain and attitudes about dental treatment) [18,19] were not measured; therefore, the obtained model was considered to be a preliminary model. Secondly, causality could not be inferred from the results because of the cross-sectional design. Thirdly, the sample was highly restricted in age and gender due to the participants being from a single women's university, and the findings may not be generalizable to other subjects; to obtain a final model, additional research using community samples and having high dental fear samples and/or using longitudinal designs is warranted. Fourthly, the study was performed in class, and therefore, based on a self-reported questionnaire, social desirability bias may occur. Compared to previous studies, the mean DFS score in the present study was relatively low (approximately 35–45 [71–73], 36.5). Fifthly, reporting bias could occur because 24 participants were excluded due to incomplete data records using the listwise case deletion method [74]. Finally, items about negative experiences regarding dental fear were created by the authors, and not validated, and these dichotomous yes/no questions may be less informative than continuous data.

In conclusion, our findings suggest that extreme sensory processing patterns, except for sensation seeking, are associated with dental fear among female students. Sensory processing might be an underlying cause of dental fear as genetic and biological factors. Our potential etiological model suggests that differences in sensory processing patterns are targets for selecting effective treatment of dental fear. Additional research, involving other psychological variables, to assess differences in sensory processing patterns among highly fearful patients and to compare effectiveness of psychological and/or pharmacological interventions is needed.

Acknowledgments

We acknowledge Professor Naoki Kakudate for study design, Professor Ryoichiro Iwanaga for the terminology of sensory processing, and all the participants. The authors would like to thank Enago (www.enago.jp) for the English language review.

Disclosure statement

The authors report no conflict of interest.

Data availability

Data that support the findings of this study are available from the corresponding author, W. S., upon reasonable request.

Funding

This study was supported by competition funds from Kyushu Dental University, Kitakyushu, Japan.

References

[1] Berggren U, Carlsson SG. Qualitative and quantitative effects of treatment for dental fear and avoidance. Anesth Prog. 1986;33: 9–13.

[2] Poulton R, Thomson WM, Brown RH, et al. Dental fear with and without blood-injection fear: implications for dental health and clinical practice. Behav Res Ther. 1998;36:591–597.

[3] Crofts-Barnes NP, Brough E, Wilson KE, et al. Anxiety and quality of life in phobic dental patients. J Dent Res. 2010;89:302–306.

[4] Carlsson V, Hakeberg M, Wide Boman U. Associations between dental anxiety, sense of coherence, oral health-related quality of life and health behavior–a national Swedish cross-sectional survey. BMC Oral Health. 2015;15:100.

[5] Weinstein P, Shimono T, Domoto P, et al. Dental fear in Japan: Okayama Prefecture school study of adolescents and adults. Anesth Prog. 1992;39:215–220.

[6] Domoto P, Weinstein P, Kamo Y, et al. Dental fear of Japanese residents in the United States. Anesth Prog. 1991;38:90–95.

[7] Lahti S, Vehkalahti MM, Nordblad A, et al. Dental fear among population aged 30 years and older in Finland. Acta Odontol Scand. 2007;65:97–102.

[8] Chanpong B, Haas DA, Locker D. Need and demand for sedation or general anesthesia in dentistry: a national survey of the Canadian population. Anesth Prog. 2005;52:3–11.

[9] Milgrom P, Fiset L, Melnick S, et al. The prevalence and practice management consequences of dental fear in a major US city. J Am Dent Assoc. 1988;116:641–647.

[10] Weiner A. The fearful dental patient: A guide to understanding and managing. 1st ed. New Jersey: Wiley-Blackwell; 2011.

[11] Oliveira MA, Vale MP, Bendo CB, et al. Influence of negative dental experiences in childhood on the development of dental fear in adulthood: a case-control study. J Oral Rehabil. 2017;44: 434–441.

[12] Milgrom P, Weinstein P, Getz T. Treating fearful dental patients. 2nd ed. Washington: University of Washington; 1995.

[13] Pohjola V, Mattila AK, Joukamaa M, et al. Anxiety and depressive disorders and dental fear among adults in Finland. Eur J Oral Sci. 2011;119:55–60.

[14] Locker D, Poulton R, Thomson WM. Psychological disorders and dental anxiety in a young adult population. Commun Dent Oral Epidemiol. 2001;29:456–463.

[15] Doganer YC, Aydogan U, Yesil HU, et al. Does the trait anxiety affect the dental fear?. Braz Oral Res. 2017;31:e36.

[16] Taani D. Dental fear among a young adult Saudian population. Int Dent J. 2001;51:62–66.

[17] Heft MW, Meng X, Bradley MM, et al. Gender differences in reported dental fear and fear of dental pain. Community Dent Oral Epidemiol. 2007;35:421–428.

[18] McNeil D, Randall C. Dental fear and anxiety associated with oral health care: conceptual and clinical issues. In: Mostofsky DI, Fortune F Behavioral Dentistry. 2nd ed. Ames (IA): Blackwell; 2014. p. 89–107.

[19] Öst L, Skaret E. Cognitive Behavioral Therapy for Dental Phobia and Anxiety. Oxford (UK): Wiley-Blackwell. 2013.

[20] Armfield JM, Stewart JF, Spencer AJ. The vicious cycle of dental fear: exploring the interplay between oral health, service utilization and dental fear. BMC Oral Health. 2007;7:1.

[21] Randall CL, Shaffer JR, McNeil DW, et al. Toward a genetic understanding of dental fear: evidence of heritability. Community Dent Oral Epidemiol. 2017;45:66–73.

[22] Randall CL, McNeil DW, Shaffer JR, et al. Fear of pain mediates the association between MC1R genotype and dental fear. J Dent Res. 2016;95:1132–1137.

[23] Addicks SH, McNeil DW, Randall CL, et al. Dental care-related fear and anxiety: distress tolerance as a possible mechanism. JDR Clin Trans Res. 2017;2:304–311.

[24] Humphry R. Young children's occupations: explicating the dynamics of developmental processes. Am J Occup Ther. 2002;56: 171–179.

[25] Dunn W. The impact of sensory processing abilities on the daily lives of young children and their families: a conceptual model. Infants Young Child. 1997;9:23–25.

[26] Dunn W. The sensations of everyday life: empirical, theoretical, and pragmatic considerations. Am J Occup Ther. 2001;55: 608–620.

[27] Ben-Sasson A, Carter AS, Briggs-Gowan MJ. Sensory over-responsivity in elementary school: prevalence and social-emotional correlates. J Abnorm Child Psychol. 2009;37:705–716.

[28] Ahn RR, Miller LJ, Milberger S, et al. Prevalence of parents' perceptions of sensory processing disorders among kindergarten children. Am J Occup Ther. 2004;58:287–293.

[29] Crane L, Goddard L, Pring L. Sensory processing in adults with autism spectrum disorders. Autism. 2009;13:215–228.

[30] Polatajko HJ, Cantin N. Exploring the effectiveness of occupational therapy interventions, other than the sensory integration approach, with children and adolescents experiencing difficulty processing and integrating sensory information. Am J Occup Ther. 2010;64:415–429.

[31] Case-Smith J, Weaver LL, Fristad MA. A systematic review of sensory processing interventions for children with autism spectrum disorders. Autism. 2015;19:133–148.

[32] Aron EN, Aron A. Sensory-processing sensitivity and its relation to introversion and emotionality. J Pers Soc Psychol. 1997;73: 345–368.

[33] Miller LJ, Anzalone ME, Lane SJ, et al. Concept evolution in sensory integration: a proposed nosology for diagnosis. Am J Occup Ther. 2007;61:135–140.

[34] Brown C, Tollefson N, Dunn W, et al. The Adult Sensory Profile: measuring patterns of sensory processing. Am J Occup Ther. 2001;55:75–82.

[35] Engel-Yeger B, Dunn W. Relationship between pain catastrophizing level and sensory processing patterns in typical adults. Am J Occup Ther. 2011;65:1–10.

[36] Engel-Yeger B, Dunn W. The relationship between sensory processing difficulties and anxiety level of healthy adults. Br J Occup Ther. 2011;74:210–216.

[37] Serafini G, Gonda X, Canepa G, et al. Extreme sensory processing patterns show a complex association with depression, and impulsivity, alexithymia, and hopelessness. J Affect Disord. 2017;210: 249–257.

[38] Serafini G, Gonda X, Pompili M, et al. The relationship between sensory processing patterns, alexithymia, traumatic childhood experiences, and quality of life among patients with unipolar and bipolar disorders. Child Abuse Negl. 2016;62:39–50.

[39] Engel-Yeger B, Palgy-Levin D, Lev-Wiesel R. The sensory profile of people with post-traumatic stress symptoms. Occup Ther Mental Health. 2013;29:266–278.

[40] Stein L, Lane C, Williams M, et al. Physiological and behavioral stress and anxiety in children with autism spectrum disorders during routine oral care. Biomed Res Int. 2014;2014:694876.

[41] Cupelli ET, Escallier L, Galambos N, et al. Sensory processing differences and urinary incontinence in school-aged children. J Pediatr Urol. 2014;10:880–885.

[42] Kleinknecht R, Klepac R, Alexander L. Origins and characteristics of fear of dentistry. J Am Dent Assoc. 1973;86:842–848.

[43] Brown C, Dunn W, Tujii M, et al. Japanese Adolescent/Adult Sensory Profile User's manual. Tokyo (Japan): Nihon Bunka Kagakusha. 2015.

[44] Spielberger C, Gorsuch R, Lushene R. Manual for the State-Trait Anxiety Inventory. Palo Alto (CA): Consulting Psychologists Press; 1983.

[45] Baron-Cohen S, Wheelwright S, Skinner R, et al. The autism-spectrum quotient (AQ): evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. J Autism Dev Disord. 2001;31:5–17.

[46] Yoshida T, Milgrom P, Mori Y, et al. Reliability and cross-cultural validity of a Japanese version of the Dental Fear Survey. BMC Oral Health. 2009;9:17.

[47] Iwata N, Mishima N, Shimizu T, et al. The Japanese adaptation of the STAI Form Y in Japanese working adults-the presence or absence of anxiety. Ind Health. 1998;36:8–13.

[48] Wakabayashi A, Tojo Y, Baron-Cohen S, et al. The Autism-Spectrum Quotient (AQ) Japanese version: evidence from high-functioning clinical group and normal adults. Jpn J Psychol. 2004; 75:78–84.

[49] Vatcheva K, Lee M, McCormick J, et al. Multicollinearity in regression analyses conducted in epidemiologic studies. Epidemiology. 2016;6:227.

[50] Blunch N. Introduction to structural equation modelling using SPSS and AMOS. London: SAGE. 2008.

[51] Brown TA. Confirmatory factor analysis for applied research. New York, (US): Guilford Press; 2006.

[52] Schermelleh-Engel KH, Müller H. Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures. Method Psych Res. 2003;8:23–74.

[53] Hu L-T, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. Struct Eq Model. 1999;6:1–55.

[54] Klingberg G, Broberg AG. Dental fear/anxiety and dental behaviour management problems in children and adolescents: a review of prevalence and concomitant psychological factors. Int J Paediatr Dent. 2007;17:391–406.

[55] Arnrup K, Broberg AG, Berggren U, et al. Temperamental reactivity and negative emotionality in uncooperative children referred to specialized paediatric dentistry compared to children in ordinary dental care. Int J Paediatr Dent. 2007;17:419–429.

[56] Shapiro M, Melmed RN, Sgan-Cohen HD, et al. Effect of sensory adaptation on anxiety of children with developmental disabilities: a new approach. Pediatr Dent. 2009;31:222–228.

[57] Binkley CJ, Beacham A, Neace W, et al. Genetic variations associated with red hair color and fear of dental pain, anxiety regarding dental care and avoidance of dental care. J Am Dent Assoc. 2009;140:896–905.

[58] Sullivan MJL, Bishop SR, Pivik J. The pain catastrophizing scale: development and validation. Psychol Assessment. 1995;7:524–532.

[59] Marshall PWM, Schabrun S, Knox MF. Physical activity and the mediating effect of fear, depression, anxiety, and catastrophizing on pain related disability in people with chronic low back pain. PLoS One. 2017;12:e0180788.

[60] De Jongh A, Muris P, ter Horst G, et al. Cognitive correlates of dental anxiety. J Dent Res. 1994;73:561–566.

[61] Simons JS, Gaher RM. The Distress Tolerance Scale: Development and validation of a self-report measure. Motiv Emot. 2005;29:83–102.

[62] Reiss S. Expectancy model of fear, anxiety, and panic. Clin Psychol Rev. 1991;11:141–153.

[63] Viinikangas A, Lahti S, Tolvanen M, et al. Dental anxiety and alexithymia: gender differences. Acta Odontol Scand. 2009;67:13–18.

[64] Pohjola V, Mattila AK, Joukamaa M, et al. Dental fear and alexithymia among adults in Finland. Acta Odontol Scand. 2011;69:243–247.

[65] Ben-Avi N, Almagor N, Engel-Yeger B. Sensory processing difficulties and interpersonal relationships in adults: an exploratory study. Psych. 2012;3:70–77.

[66] Jerome E, Liss M. Relationships between sensory processing style, adult attachment, and coping. Personal Individ Differ. 2005;38: 1341–1352.

[67] Fuentes D, Gorenstein C, Hu LW. Dental anxiety and trait anxiety: an investigation of their relationship. Br Dent J. 2009;206:E17.

[68] Shah D. Healthy worker effect phenomenon. Indian J Occup Environ Med. 2009;13:77–79.

[69] Hagglin C, Hakeberg M, Ahlqwist M, et al. Factors associated with dental anxiety and attendance in middle-aged and elderly women. Comm Dent Oral Epidemiol. 2000;28:451–460.

[70] Hagglin C, Hakeberg M, Hallstrom T, et al. Dental anxiety in relation to mental health and personality factors. A longitudinal study of middle-aged and elderly women. Eur J Oral Sci. 2001;109:27–33.

[71] Sano T, Tanabe Y, Noda T. Assesment of dental fear in Japan - part 1 results of dental fear survey in young adults. Jpn J Ped Dent. 2001;39(4):865–871.

[72] Hakim H, Razak IA. Dental fear among medical and dental undergraduates. Sci World J. 2014;2014:1.

[73] Oliveira MA, Vale MP, Bendo CB, et al. Dental Fear Survey: a cross-sectional study evaluating the psychometric properties of the Brazilian Portuguese version. Sci World J. 2014;2014:1.

[74] Roth PL. Missing data: A conceptual review for applied psychologists. Pers Psychol. 1994;47:537–560.

Appendix 1. Correlations between variables using Spearman's ρ and variance inflation factor ($N = 310$).

		1	2	3	4	5	6	7	8	VIF
1	DFS									
2	Sensory sensitivity	0.371**								2.059
3	Sensory avoidance	0.273**	0.618**							1.832
4	Low registration	0.238**	0.506**	0.438**						1.736
5	Sensation seeking	−0.082	0.119*	0.011	0.160**					1.411
6	Age	−0.044	0.036	0.092	−0.051	−0.046				1.041
7	STAI (State)	0.148**	0.210**	0.199**	0.132*	−0.196**	0.086			1.736
8	STAI (Trait)	0.225**	0.330**	0.343**	0.346**	−0.257**	0.010	0.588**		3.010
9	AQ	0.200**	0.288**	0.342**	0.343**	−0.334**	−0.110	0.265**	0.518**	1.659

**$p < .01$; *$p < .05$.
DFS: Dental Fear Survey; GAS: Gagging Assessment Scale; STAI: State–Trait Anxiety Inventory; AQ: Autism–Spectrum Quotient; VIF: Variance Inflation Factor.

Appendix 2. Results of structural equation modelling.

Relations			Hypothetical		Modified	
Multiple regression analysis			β	*p*	β	*p*
Dental fear	←	Sensory processing	0.282	.002	0.377	<.001
Dental fear	←	Negative experiences	0.388	<.001	0.357	<.001
Dental fear	←	Trait anxiety	0.057	.362	—	—
Dental fear	←	Autism-Spectrum Quotient	0.065	.335	—	—
Dental fear	←	Age	−0.006	.928	—	—
Dental fear	R-SQUARE		0.351	<.001	0.356	<.001
Sensory processing	←	Negative experiences	0.354	<.001	0.322	<.001
Sensory processing	←	Autism-Spectrum Quotient	0.397	<.001	0.463	<.001
Sensory processing		R-SQUARE	0.283	<.001	0.319	<.001
Trait anxiety	←	Sensory processing	0.285	<.001		
Trait anxiety	←	Autism-Spectrum Quotient	0.401	<.001	0.363	<.001
Trait anxiety	R-SQUARE		0.333	<.001	0.348	<.001
Factor analysis			Factor loading	*p*	Factor loading	*p*
Sensory sensitivity	←	Sensory processing	0.860	<.001	0.821	<.001
Sensory avoidance	←	Sensory processing	0.719	<.001	0.721	<.001
Low registration	←	Sensory processing	0.641	<.001	0.627	<.001
Sensation seeking	←	Sensory processing	0.178	.004	—	—
Painful dental treatment	←	Negative experiences	0.593	<.001	0.607	<.001
Painful medical treatment	←	Negative experiences	0.426	<.001	0.430	<.001
Dental treatment by scary dentist	←	Negative experiences	0.508	<.001	0.515	<.001
Family's dental fear	←	Negative experiences	0.643	<.001	0.656	<.001
Seeing scary dentist in the media	←	Negative experiences	0.485	<.001	0.491	<.001
Avoidance	←	Dental fear	0.907	<.001	0.907	<.001
Physiological arousal	←	Dental fear	0.844	<.001	0.843	<.001
Fears of specific situations	←	Dental fear	0.835	<.001	0.836	<.001
Correlation analysis			*r*	*p*	*r*	*p*
Age	↔	Negative experiences	0.016	.875	—	—
Age	↔	Sensory processing	0.002	.965	—	—
Age	↔	Trait anxiety	0.044	.359	—	—