Research in Developmental Disabilities 45–46 (2015) 157–167

Contents lists available at ScienceDirect

Research in Developmental Disabilities

Ecological aspects of pain in sensory modulation disorder

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ARTICLE INFO

Article history:
Received 27 November 2014
Received in revised form 24 July 2015
Accepted 28 July 2015
Available online

Keywords:
Sensory modulation disorder (SMD)
Sensory over-responsivity (SOR)
Pain sensitivity
Pain catastrophizing
Quality of life (QoL)

ABSTRACT

Background: Sensory Modulation Disorder (SMD) interferes with the daily life participation of otherwise healthy individuals and is characterized by over-, under- or seeking responsiveness to naturally occurring sensory stimuli. Previous laboratory findings indicate pain hyper-sensitivity in SMD individuals suggesting CNS alteration in pain processing and modulation. However, laboratory studies lack ecological validity, and warrant clinical completion in order to elicit a sound understanding of the phenomenon studied. Thus, this study explored the association between sensory modulation and pain in a daily life context in a general population sample.

Methods: Daily life context of pain and sensations were measured in 250 adults (aged 23–40 years; 49.6% males) using 4 self-report questionnaires: *Pain Sensitivity Questionnaire (PSQ)* and *Pain Catastrophizing Scale* (PCS) to evaluate the sensory and cognitive aspects of pain; the *Sensory Responsiveness Questionnaire* (SRQ) to appraise SMD; and the *Short Form – 36 Health Survey, version 2 (SF36)* to assess health related Quality of Life (QoL).

Results: Thirty two individuals (12.8%) were found with over-responsiveness type of SMD, forming the SOR-SMD group. While no group differences (SOR-SMD vs. Non-SMD) were found, low-to-moderate total sample correlations were demonstrated between the SRQ-Aversive sub-scale and i) PSQ total ($r = 0.31$, $p < 0.01$) and sub-scales scores ($r = 0.27$–0.28, $p < 0.01$), as well as ii) PCS total and the sub-scales of Rumination and Helplessness scores ($r = 0.15$, $p < 0.05$). PSQ total and sub-scale scores were more highly correlated with SRQ-Aversive in the SOR-SMD group ($r = 0.57$–0.68, $p = 0.03$–<0.01) compared to Non-SMD group. The *Physical Health – Total* score (but not the *Mental Health – Total*) of the SF36 was lower for the SOR-SMD group ($p = 0.03$), mainly due to the difference in the *Body pain* sub-scale ($p = 0.04$).

Conclusions: Results suggest that SOR-SMD is strongly associated with the sensory aspect of pain but weakly associated with the cognitive aspect. This indicates that SMD co-occurs with daily pain sensitivity, thus reducing QoL, but less with the cognitive-catastrophizing manifestation of pain perception.

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http://dx.doi.org/10.1016/j.ridd.2015.07.028
0891-4222/

1. Introduction

Sensory Modulation Disorder (SMD), a subtype of sensory processing disorder, is a generalized disorder that affects modulation across single or several sensory systems (Bundy & Murray, 2002; ICDL, 2005; Kimball, 1993; Miller, Anzalone, Lane, Cermak, & Osten, 2007; PDM, 2006; Zero, 2005). There are three sub-types of SMD: (1) sensory seeking or craving in which the individual seeks an unusual amount or type of sensation and seems to have an insatiable craving for sensation (ICDL, 2005; Miller et al., 2007; PDM, 2006; Zero, 2005); (2) sensory under-responsivity, clinically demonstrated by delayed and/or decreased responses to external stimulation (Ahn, Miller, Milberger, & McIntosh, 2004; Bar-Shalita, Vatine, & Parush, 2008; Fisher & Dunn, 1983; ICDL, 2005; Kinnealey, Oliver, & Wilbarger, 1995; Miller et al., 2007; PDM, 2006; Reeves, 2001; Zero, 2005); and (3) sensory over-responsivity (SOR-SMD), a condition in which non-painful stimuli are processed as abnormally irritating, unpleasant (Fisher & Dunn, 1983; ICDL, 2005; Kinnealey et al., 1995; Miller et al., 2007; PDM, 2006; Reynolds & Lane, 2008; Zero, 2005), or painful (Bar Shalita, Vatine, Seltzer, & Parush, 2009; Bar-Shalita, Vatine, Yarnitsky, Parush, & Weissman-Fogel, 2014; Fisher & Dunn, 1983; Reeves, 2001).

Indeed, Bar Shalita, Vatine, et al. (2009) found that subjects with SOR-SMD, demonstrated hyper-sensitivity in response to laboratory quantitative sensory testing (QST) of suprathreshold pain stimuli. The authors found that children and adults with SMD rated these stimuli as more painful compared to control subjects. Moreover, they reported that the lingering sensations were both more intense and longer than those of controls, suggesting alterations in pain processing and modulation (Bar Shalita, Vatine, et al., 2009). These laboratory findings are important evidence of pain perception alterations in SMD subjects. However, despite these people clinically demonstrating extreme hypersensitivity, they are not defined as pain patients, and so are considered to be pain-free subjects.

Pain is a complex multidimensional experience comprised of sensory, affective, and cognitive processes (Moayedi & Davis, 2013). Different aspects of the painful event such as contextual factors, environmental factors, and prior experience, can modulate pain processing and may have different impacts on the different dimensions of pain. Moreover, painful events in real-world situations are not isolated and often occur in conjunction with input from additional sensory modalities. Thus, it is essential to understand pain processing in naturalistic multisensory environments. The usual deliberately restricted laboratory conditions, under which standard well-designed studies are carried out, have a drawback in that they lack 'ecological validity', or generalizability to real life (Rollman, 2005). Thus experimental induced pain in the laboratory, which characterizes population sub-groups such as SMD, is not necessarily valid beyond the laboratory.

Therefore, in this study, we aimed to validate the laboratory pain findings in SMD via ecological assessments by using pain-related questionnaires in the general population. These questionnaires included the Pain Sensitivity Questionnaire (PSQ) and the Pain Catastrophizing Scale (PCS) that make use of typical and common painful events that occur in everyday life, in order to evaluate sensory and cognitive aspects of pain perception. The PSQ was proposed as an alternative tool to experimental pain intensity rating procedures for evaluating pain sensitivity in healthy subjects and chronic pain patients (Ruscheweyh, Marziniak, Stumpenhorst, Reinholz, & Knecht, 2009; Ruscheweyh et al., 2012). Pain catastrophizing (measured on the PCS), is characterized by amplification of feelings about painful situations and constant thoughts about these situations (Meyer, Tschopp, Sprott, & Mannion, 2009), and is described as a cognitive process involving the tendency to exaggerate and misinterpret the threat value of situations (Van Damme, Crombez, Bijttebier, Goubert, & Van Houdenhove, 2002).

While the probability of SMD rises in populations with neurodevelopmental conditions, such as Autism and ADHD (Ben-Sasson et al., 2007; Chang et al., 2014; Parush, Sohmer, Steinberg, & Kaitz, 2007), it is estimated that 5–16% of the typical pediatric population demonstrates SMD (Ahn et al., 2004; Ben-Sasson, Carter, & Briggs-Gowan, 2009; Schaaf, Miller, Seawell, & O'Keefe, 2003). Though occurring in adulthood (Bar-Shalita, Seltzer, Vatine, Yochman, & Parush, 2009; Brown, Tollefson, Dunn, Cromwell, & Filion, 2001; Kinnealey et al., 1995) prevalence of SMD in adults had not yet been reported. SMD subjects experience the environmental stimuli as irritating, aversive, unpleasant and painful that it often interferes with participation in daily life (Bar-Shalita et al., 2008; Dunn, 2007), which may impact their quality of life (QoL). Indeed, lower scores in QoL measures have been documented in children and their families as well as in adults reporting SOR (Carter, Ben-Sasson, & Briggs-Gowan, 2011; Kinnealey, Koenig, & Smith, 2011). However, a better understanding of the association between sensory responsiveness and pain perception in the context of daily living and QoL is warranted. This understanding may yield new research directions aimed at investigating possible therapeutic interventions for SMD individuals based on pain mechanisms.

Thus, this study aims at exploring in an ecological fashion the association between sensory responsiveness, pain perception and QoL in subjects from the general population, with and without SMD. A secondary purpose was to culturally adapt and initially test the Hebrew version of the PSQ.

2. Materials and methods

This research was approved by the review committee at the Hebrew University of Jerusalem, and all participants completed and signed a consent form before enrolling in the study.

2.1. Participants

A non-referred convenience sample of 258 adults, recruited from the general population, participated in this study. Exclusion criteria included pregnancy, frequent or chronic pain conditions, neurodevelopmental conditions including autism and ADHD, neurological deficits including speech, vision, hearing or behavioral abnormalities, and any family history (in siblings, parents, and/or grandparents) of psychopathology.

Group placement was based on the Sensory Responsiveness Questionnaire-Intensity Scale (SRQ-IS) scores (Bar Shalita, Vatine, et al., 2009). The comparison group included participants who scored within the normal cut-off scores for the SRQ-IS, while the group with atypical sensory modulation consisted of those who scored two standard deviations above the mean of the SRQ-IS cut-off score for over-responsiveness. Thus we included subjects that were diagnosed with the over-responsivity subtype of SMD solely (referred to as a SOR-SMD group), while SUR-SMD, scoring two standard deviations above the mean of the SRQ-IS cut-off score for under-responsiveness were removed from the study; $N = 8$; 3.1%), leaving us with remaining sample size of $N = 250$. The 2 SD cut-off score was used to ensure cautious estimation of the SMD prevalence (see below). This sample size of 250 subjects enables the detection of a correlation coefficient of 0.2 or higher with 90% power at a 2-sided 5% level of significance.

2.2. Instrumentation

2.2.1. The Sensory Responsiveness Questionnaire-Intensity Scale (SRQ-IS) (Bar-Shalita, Seltzer, et al., 2009)

Sensory responsiveness was measured using the SRQ-IS, a standard reliable and valid self-report questionnaire assessing responses to daily sensations, with the aim of clinically identifying SMD in adolescents and adults ages fourteen and up (Bar-Shalita, Seltzer, et al., 2009; Bar-Shalita, Vatine, Seltzer, & Parush, 2012). The SRQ-IS presents a set of 58 items that represent typical scenarios encountered occasionally throughout daily life. Each scenario involves one sensory stimulus in one modality, including auditory, visual, gustatory, olfactory, vestibular and somatosensory stimuli (excluding pain). The items are worded in a manner that attributes a hedonic/aversive valence to the situation (e.g., It bothers me the way new clothes feel). The participant rates the intensity of the hedonic/aversive response to the situation using a 5 point scale with the anchors '*not at all*' attached to the score of '1' and '*very much*' attached to the score of '5'. The SRQ has been demonstrated to have content, criterion and construct validity, as well as internal consistency (Cronbach $\alpha = 0.90–0.93$) and test–retest reliability ($r = 0.71–0.84$; $p < 0.01–0.05$; (Bar-Shalita, Seltzer, et al., 2009).

The SRQ elicits a score for each of the two SMD sub-types: SOR sub-type is determined by applying the SRQ-Aversive score (32 items), for which scores are higher than the normal mean cut-off score (+2 SD; 1.87 + 0.52). SUR subtype is determined by applying the SRQ-Hedonic score (26 items), for which scores are higher than the normal mean cut-off score (+2 SD; 2.10 + 0.66). In this study the SMD group was comprised of only subjects scoring above 2 SD for the SRQ-Aversive score, thus the SMD group is referred to as the SOR-SMD group.

2.2.2. The Pain Catastrophizing Scale (PCS) (Sullivan, Bishop, & Pivik, 1995)

Pain catastrophizing level was assessed by PCS, a standard, reliable and valid self-report questionnaire, that provides ratings based on painful life situations. Pain catastrophizing is conceptualized by cognitions of the inability to tolerate painful situations, thinking pain is unbearable, or ruminating on the worst possible outcome from the experienced pain (Sullivan et al., 2001).

The instrument includes 13 items representing the three components of pain catastrophizing: rumination (e.g., "I can't seem to keep it out of my mind."); magnification (e.g., "I wonder whether something serious may happen."); and helplessness (e.g., "There is nothing I can do to reduce the intensity of pain."). Participants are asked to complete the questionnaire in reference to a previous pain event, and indicate the degree to which they experienced the 13 thoughts or feelings during the event on a 5-point Likert scale ranging from 0 ('*not at all*') to 4 ('*always*'). The PCS provides a total score and three subscale scores assessing: (1) rumination, (2) magnification, and (3) helplessness. The psychometric data of the PCS has shown high internal consistency (Cronbach's $\alpha = .87$) and test–retest reliability ($r = 0.75$). Items within each subscale are strongly related to each other (Osman et al., 1997). The PCS has been validated into Hebrew (Cronbach's α for the total score (entire scale) = .86; rumination = 0.93; helplessness = .92; magnification = 0.65 (Granot & Ferber, 2005).

2.2.3. The Pain Sensitivity Questionnaire (PSQ) (Ruscheweyh et al., 2009)

Pain sensitivity level was assessed by the PSQ, a standard, reliable and valid 17 item self-report questionnaire based on pain intensity ratings of imagined painful daily life situations in different somatosensory sub-modalities. Fourteen of the items relate to situations that are painful for the majority of persons covering a variety of different types of pain (e.g. hot, cold, sharp, and blunt). The other three items (items 5, 9, 13) describe normally non-painful situations (e.g. taking a warm shower). The latter items are interspersed among the 'painful' items to serve as non-painful sensory reference for the subjects. Pain intensity is rated on a scale with the anchors '*not painful at all*' attached to the score of '0' and '*worst pain imaginable*' attached to the score of '10'. The PSQ provides a total score (*PSQ-total*) and two subscale scores *PSQ-moderate* and *PSQ-minor*. The PSQ has been demonstrated to have content, criterion and construct validity, as well as internal consistency (Cronbach's $\alpha = 0.92$ for *PSQ-total*, 0.81 for *PSQ-minor* and 0.91 for *PSQ-moderate*), and test–retest reliability (ICCs = 0.83, 0.86 and 0.79, respectively).

Since the Hebrew version of the PSQ was not tested for psychometric properties, cultural adaptation and initial testing of the Hebrew version was required. Psychometric testing followed those reported by test developers (Ruscheweyh et al., 2009), while also aiming at adapting the questionnaire in a culturally relevant and comprehensible way, while keeping with the original meaning of items (Sperber, Devellis, & Boehlecke, 1994).

2.2.4. The Short Form – 36 Health Survey, version 2 (SF36) (Ware, Kosinnski, & Gandek, 2005)

Health related quality of life (QoL), was assessed using the SF36, a standard, reliable and valid self-report questionnaire, which discriminates between ranges of disability (Jason et al., 2011). This is a short-form, multipurpose generic health survey that elicits health and well-being scores in eight areas, together comprising two total scores of physical health (*physical functioning, role physical, bodily pain, and general health*), and mental health (*vitality, social functioning, role emotional, and mental health*). The SF36 has been extensively used in social science and health related research with psychometric properties widely reported in the literature (Ware et al., 2005). Items require responses on scales that range from 2 to 6 points. Respondents are asked to think about the past month when answering. This questionnaire has been standardized into Hebrew. Results demonstrated reliability (Cronbach's α ranged from 0.76 to 0.93) and construct validity (Lewin-Epstein, Sagiv-Schifter, Shabtai, & Shmueli, 1998).

2.3. Procedure

Adult volunteers who agreed to be informed about the study were contacted by phone. The purpose of the study and other preliminary information was provided by the researcher and exclusion criteria were verified. Thereafter, an appointment at the participants' convenience was made. After completing a consent form and a medical and demographic questionnaire that attained medical and demographic information about the participants and their families, the SRQ, PSQ, PCS and SF36 were introduced. These questionnaires were completed in a random order to avoid sequential effects and to balance the possible influence of fatigue and attention span. This meeting lasted for approximately 45 min, during which time the researcher remained in the same room, available to answer questions if needed.

2.4. Data analysis

Statistical analyses were performed with SAS V9.3 (SAS Institute, Cary NC, USA).

At first we demonstrated the psychometric properties for the PSQ, internal consistency and construct validity data via Cronbach's α, principal component analysis and correlation analyses which are presented in Table 1.

Study data is presented in Tables and Figures. Continuous variables were summarized by means and standard deviations and compared with a *t*-test (normality was assessed as well as homogeneity of variances). Categorical variables were summarized by a count and percentage, and compared with a chi-squared test, or Fisher's exact test when appropriate. Pearson correlation coefficients were calculated between SRQ, PSQ and PCS scores in each of the groups. Correlations were compared between the groups using Fisher's *z* transformation where they were then treated as normal random variables. All statistical tests were two-sided and tested at a 5% level of significance. Nominal *p*-values are presented.

3. Results

3.1. Adapting the PSQ to the Israeli population

No differences were found in scores between males and females ($p = 0.32$), similar to that reported by Ruscheweyh et al. (2009).

Reliability testing: After translation and back-translation were administered, Internal Consistency, via Cronbach's alpha was calculated. We found a high item homogeneity for the PSQ adapted version (Cronbach's $\alpha = .9210$). To further examine the PSQ reliability, factor analysis was carried out to test whether scores distribute into the two original factors (Ruscheweyh et al., 2009). Principal Component analysis yielded two factors: Factor 1 accounted for 33% of the variance and was constituted by items rated as moderately painful, while Factor 2 was constituted by items rated as minor pain and accounted

Table 1
Convergence and divergence validity (Pearson correlation coefficients) of the PSQ[a] and PCS[b] sub-scales.

PSQ subscales	PSQ-moderate	PSQ-minor	PCS total	PCS rumination	PCS magnification	PCS helplessness
PSQ-total	0.94***	0.94***	0.24**	0.23**	0.115	0.23**
PSQ-moderate		0.80***	0.21*	0.20	0.11	0.21*
PSQ-minor			0.25**	0.24**	0.10	0.25**

[a] PSQ-Pain Sensitivity Questionnaire.
[b] PCS-Pain Catastrophizing Scale.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.0001$.

for 18% of variance. Item distribution between the two factors was similar to that reported by test developers (Ruscheweyh et al., 2009). Overall variance of the two factors was also similar and accounted for 52% and 56%, respectively

Validity testing: Construct validity was further tested to examine the extent of the sub-scales convergence and discriminability using multivariate pairwise correlations. High correlations were found within the PSQ total and subscales indicating convergence validity ($r = 0.80–.94$), while low correlations were found between the PCS and PSQ subscales indicating divergence validity (see Table 1). The highly significant results of the convergence analysis of the PSQ sub-scales (i.e., Total, Moderate and Minor) clearly support the contention that these variables test the same construct. The low correlations in the discriminability analysis suggest that the two questionnaires hold different constructs which represent different aspects of the pain phenomenon.

In summary, the Hebrew version testing results were found similar to those reported in tool development (Ruscheweyh et al., 2009). Thus the Hebrew PSQ is a valid and reliable unique measure for daily pain sensitivity.

3.2. Sample distribution

Mean (standard deviation; SD) age found was 27.3 (3.77) years, (range 23–40 years), and 49.6% were male. We found that 12.8% (32/250) of subjects tested met the criterion for SOR-SMD, with the remaining 87.2% (218) in the Non-SMD group. No significant differences were found between the study groups with respect to sex distribution ($p = 0.96$). Mean (SD) age for the SMD and Non-SMD were also similar 28.7 (SD = 4.76) and 27.1 (SD = 3.57) years, respectively ($p = 0.09$).

3.3. Characterizing the whole sample by SRQ, PCS, and PSQ

Low, though statistically significant, correlations were found between the SRQ-Aversive and three out of the four PCS scores. No correlations were found between SRQ-Hedonic and PCS scores (see Table 2; Fig. 1). No group differences were found between SOR-SMD and Non-SMD for the total and three PCS subscales ($p = 0.19–0.46$). Similar to the above, statistically significant correlations were found between the SRQ-Aversive score and each of the PSQ total and sub-scales, but not with the SRQ-Hedonic score (see Table 2; Figure 1). No statistically significant differences were found between the SOR-SMD and Non-SMD groups for the total and three PSQ subscales ($p = 0.08–0.34$).

3.4. PSQ and PCS in SOR-SMD and Non-SMD participants

Correlations between PSQ and SRQ-Aversive scores were statistically significant within each group (SOR-SMD; Non-SMD) (Table 3). Moreover, between-group comparisons of these correlations (SOR-SMD vs Non-SMD) showed a significantly higher correlation in the SOR-SMD (Table 3; Fig. 2). When considering correlations between PCS and SRQ-Aversive scores, only the total PCS score was found significantly correlated with SRQ-Aversive), however, there were no group differences for any of the PCS correlations (Table 3).

3.5. SF36 in SOR-SMD and Non-SMD participants

While the SOR-SMD group scored lower on all SF36 sub-scales (lower QoL) compared to the Non-SMD group, this only reached significance for the total score of *Physical Health*. Within this domain, the score for *Body Pain* subscale was significantly higher in the SOR-SMD group and reached statistical significance (see Table 4). Though the mental health sub-scale reached statistical significance, the total score of the *Mental Health* domain did not differ between the groups. There were no other significant group differences in the SF36.

Table 2
Pearson correlation coefficients between the SRQ[a] scores and the PCS[b] and PSQ[c] total and sub-scores (with level of significance of each coefficient) ($N = 250$).

PCS and PSQ	SRQ aversive	hedonic
PCS total	0.15*	−0.06
PCS rumination	0.15*	−0.12
PCS magnification	0.08	0.03
PCS helplessness	0.15*	−0.03
PSQ total	0.31**	−0.02
PSQ-moderate	0.28**	−0.00
PSQ-minor	0.28**	−0.06
PSQ-non-painful	0.27**	0.07

[a] SRQ – Sensory Responsiveness Questionnaire.
[b] PCS – Pain Catastrophizing Scale.
[c] PSQ – Pain Sensitivity Questionnaire.
* $p < 0.05$.
** $p < 0.001$.

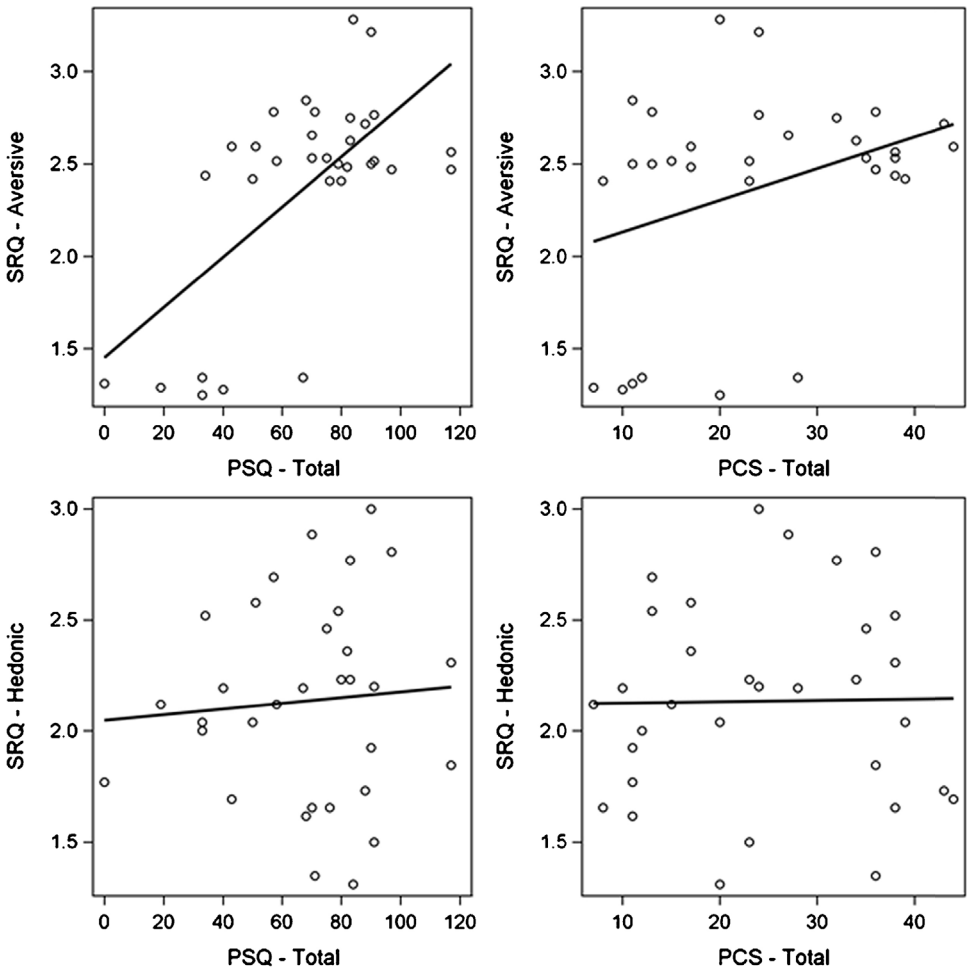

Fig. 1. Pearson correlation coefficients between both *SRQ* scores (*Aversive* and *Hedonic*) and the *PSQ Total* (left) and *PCS Total* (right) scores ($N = 250$).

4. Discussion

In this study we investigated multisensory perception in SMD by testing the association between sensory responsiveness and pain perception in the context of daily life. Sensory responsiveness was tested via the affective aspect (SRQ), while pain

Table 3
Pearson correlation coefficients of the SRQ[a]-aversive score and the PSQ[b] (*Total, Moderate, Minor and Non-painful)* and PCS[c] (Total, Rumination, Magnification, Helplessness) scores (with level of significance of each coefficient) and the correlation comparison between Non-SMD ($N = 218$) and SOR-SMD ($N = 32$) (p values).

PSQ and PCS	Pearson correlation coefficients: SRQ-Aversive		Comparison of correlation between groups p-values
	Non-SMD	SOR-SMD	
PSQ – Moderate	0.13*	0.68***	<**0.01**
PSQ – Minor	0.20*	0.57**	**0.03**
PSQ – Non painful	0.19*	0.41*	0.22
PSQ – Total score	0.19*	0.65***	<**0.01**
PCS – Rumination	0.09	0.32	0.22
PCS – Magnification	−0.00	0.21	0.28
PCS – Helplessness	0.07	0.34	0.16
PCS – Total score	0.08	0.35*	0.14

* $p < 0.05$.
*** $p < 0.0001$.
[a] SRQ – Sensory Responsiveness Questionnaire.
[b] PSQ – Pain Sensitivity Questionnaire.
[c] PCS – Pain Catastrophizing Scale.

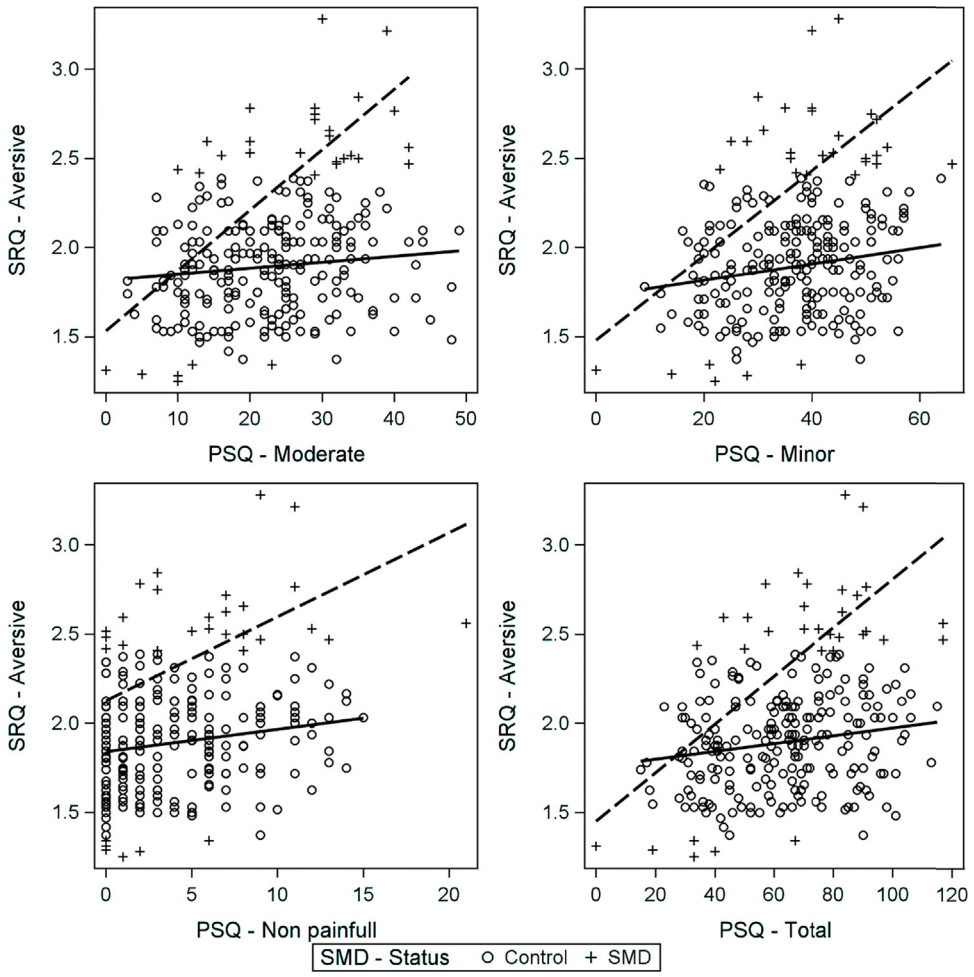

Fig. 2. Scatter plots of the SRQ-Aversive score versus the PSQ scores (Total, Moderate, Minor and Non-painful).

perception was studied via the sensory and cognitive aspects (PSQ and PCS, respectively). The cultural adaptation of the PSQ yielded similar psychometric properties to those reported by test developers, presenting a reliable and valid PSQ – Hebrew version, for evaluating daily pain sensitivity. We tested a general population sample and found low correlations between the three measures: PSQ, PCS, and SRQ-Aversive. However, no correlations were found between pain perception measures (PSQ, PCS) and SRQ-Hedonic. These findings suggest that in a daily life context, the interactive effects of pain sensitivity and catastrophizing with the affective aspect of the sensory perception, occur only with aversive responsiveness. Interestingly, when dividing the sample into those with or without SOR (SOR-SMD and Non-SMD groups), the correlations between pain sensitivity and aversive responsiveness were strengthened to a moderately high level in the SOR-SMD group. Overall, these results suggest that SOR-SMD is strongly associated with the sensory aspect of pain but weakly with the cognitive aspect, indicating that the sensory modulation disorder co-occurs with daily pain sensitivity but less so with the cognitive-catastrophizing manifestation of pain perception.

Previous reports (Bar Shalita, Vatine, et al., 2009) show that SMD subjects demonstrate hypersensitivity to experimental pain measures compared to non-SMD subjects, however, the current study did not demonstrate greater pain sensitivity in SOR-SMD subjects. Thus the pain sensitivity of subjects with SOR might be modulated differently in everyday life compared to laboratory environments. We suggest that multisensory processing that occurs in daily situations is a factor that impacts the pain sensitivity of subjects with SOR-SMD. A laboratory human model that imitates multisensory environment found that SOR-SMD subjects integrate simultaneous multimodal somatosensory and auditory stimulation differently in both location and time course (Brett-Green, Miller, Schoen, & Nielsen, 2010). These functional results are further supported by structural findings of white matter integrity reduction in the primary sensory cerebral tracts and pathways associated with atypical multisensory integration behavior (Owen et al., 2013). This could provide an anatomical basis for the hypothesis relating SMD with atypical neurophysiological responses to multisensory stimuli. Psychophysical findings suggest abnormal pain modulation processes in SMD subjects

Table 4
Comparison of SF-36 sub-scale scores and both Physical and Mental health total scores in SOR-SMD ($N = 32$) and Non-SMD ($N = 218$) participants (t-test; df = 248).

SF36 sub-scales		Mean	SD	*t* value	Between-group comparison *p*-value
Physical function	Non-SMD	95.3	8.05	1.70	0.09
	SOR-SMD	92.7	9.84		
Role physical	Non-SMD	88.4	24.84	1.34	0.18
	SOR-SMD	82.0	27.85		
Body pain	Non-SMD	80.2	21.20	2.11	**0.04**
	SOR-SMD	71.8	18.40		
General health	Non-SMD	79.5	17.97	1.49	0.14
	SOR-SMD	74.5	16.75		
Vitality	Non-SMD	54.7	17.65	1.15	0.25
	SOR-SMD	50.8	20.04		
Social functioning	Non-SMD	84.5	20.74	1.04	0.30
	SOR-SMD	80.5	19.81		
Role emotional	Non-SMD	77.2	35.72	1.10	0.27
	SOR-SMD	69.8	34.24		
Mental health	Non-SMD	69.2	18.00	2.45	**0.01**
	SOR-SMD	60.8	20.36		
Physical health – total[a]	Non-SMD	79.6	12.64	2.18	**0.03**
	SOR-SMD	74.4	13.51		
Mental health – total[b]	Non-SMD	73.0	17.13	1.79	0.07
	SOR-SMD	67.3	16.30		

[a] Physical Health – Total comprises the sub-scales of Physical Function; Role Physical; Body Pain; General Health.
[b] Mental Health – Total comprises the sub-scales of Vitality; Social Functioning; Role Emotional; Mental Health.

demonstrated by hyperalgesia and higher after-sensation (Bar-Shalita et al., 2014). These findings may evoke the behavioral defensive responses to sensory input reported in SOR-SMD subjects, which serve as coping strategies (Bundy & Murray, 2002; Dunn, 2007; Miller et al., 2007). These coping strategies are utilized to prevent a further barrage of noxious information to the already bombarded and irritated sensory system, and shield the SOR-SMD subjects from experiencing augmented multisensory interaction.

In the current study, we found links between the degree of pain sensitivity and sensory (non-painful) responsiveness perception. While no association was found for the hedonic responsiveness perception, an increasing association was found within the sensory aversive responsiveness spectrum. Specifically, a low level of correlation was found within the normal range of aversive responsiveness to daily stimuli (i.e. non-SMD), which increased to a high degree of correlation with a high level of sensory over-responsivity (i.e. SOR-SMD). This suggests cross-modal processing (Spence, Senkowski, & Roder, 2009), and highlights the important role of innocuous unpleasant stimuli in the peripersonal space in shaping pain perception (Senkowski, Hofle, & Engel, 2014). In summary, multisensory information processing, which is part of our daily life, brings about multisensory integration (or cross-modal processes) that affects our behavioral responses. The valence of the stimuli surrounding us influences pain processing and modulation whereby unpleasant affective experiences of different modalities (e.g. vision, audition, and olfaction) have been found to enhance pain perception (Senkowski et al., 2014). Anatomically, the integration of negative affect and pain occurs in the anterior midcingulate cortex (aMCC) (Shackman et al., 2011). The aMCC is a primary cortical target of the spinothalamic tract transmitting somatosensory input including pain (Dum, Levinthal, & Strick, 2009). It is connected with the lateral periaqueductal gray (Klionsky et al., 2008) that is involved in defensive responses (An, Bandler, Ongur, & Price, 1998), and the amygdala that is implicated in negative affect processing (Ghashghaei, Hilgetag, & Barbas, 2007), as well as with the posterior parietal cortex, an area that integrates pain input with other sensory modalities (Vogt & Pandya, 1987). Thus, the multidimensional processes of negative affect and pain are implemented in distributed neural networks (Shackman et al., 2011). Pain establishes emotional valence and directs response priorities; for example, aversively motivated behaviors, which may shape the daily life of SOR-SMD subjects. Our findings that the strength of the unpleasant experience of environmental stimuli from different modalities (such as: tactile, auditory and vision), is associated with enhanced pain perception, is in line with the integration principles that are of general relevance in multisensory perception (Senkowski et al., 2014). Although no causal relationships can be concluded from this interrelationship, the fact that the individual pain sensitivity is associated in different ways with the hedonic and aversive dimensions of the sensory responsiveness, implies that this association is attributed to the influence of the sensory responsiveness on pain perception, and not vice versa.

Catastrophizing has a significant role in theories of pain chronicity, demonstrating a consistent association with pain intensity as well as disability, and explaining the variance in experimental pain perception found in healthy subjects (Edwards, Bingham, Bathon, & Haythornthwaite, 2006). In line with a previous study by Ruscheweyh et al. (2009) we found a positive correlation between pain catastrophizing (evaluated by the PCS) and pain sensitivity (evaluated by the PSQ). The latter was also found to be highly correlated with experimental pain intensity ratings (Ruscheweyh et al., 2009).

Furthermore, the current study found low correlations between PCS and aversive responsiveness, suggesting pain related cognitive thoughts, such as rumination and helplessness, are also associated to some degree with augmented sensory unpleasant perception. Interestingly, within the sensory aversive responsiveness to daily stimuli spectrum, no correlation was found within the normal range (i.e. non-SMD), but a moderate degree of correlation was observed with a high level of sensory over-responsivity (i.e. SOR-SMD). These interrelationships might contribute to the understanding of the SMD phenomenon of over responsivity. Neurophysiologically, convergent multi-sensory input, via the parietal-limbic pathway, projects to the prefrontal cortex that is engaged in rumination and helplessness thoughts (Kucyi et al., 2014; Qiao et al., 2013; Taylor et al., 2014; Vogt & Pandya, 1987; Wang, Perova, Arenkiel, & Li, 2014), and thus contributes to the persistent experience of the environmental stimuli as aversive, unpleasant and even painful in SMD-SOR subjects. The aMCC may serve this function by coordinating input from parietal areas involved in perception of bodily threats (Legrain, Iannetti, Plaghki, & Mouraux, 2011), with frontal cortical areas involved in plans and response priorities for pain-related behaviors, which in turn may explain avoidance learning in SOR-SMD subjects (Dunn, 2001; Kinnealey et al., 1995). Importantly, no difference was found between the SOR-SMD and non-SMD subjects for the PCS score, contrary to a previous study that measured sensory responsiveness with a different questionnaire (Engel-Yeger & Dunn, 2011). These results together with the absence of a group difference in PSQ scores imply that SMD-SOR and non-SMD are not distinct groups but rather represent different anchors within a continuum of sensory responsiveness. Within the range of sensory over-responsivity, the cognitive and especially the sensory dimensions of pain are linked to an excessive degree of unpleasantness associated with non-painful daily events, which may subsequently affect the level of daily painful experience.

We found a reduction in QoL in the SOR-SMD group validating other reports. However, Kinnealey et al. (2011) applying the same measure, reported lower scores in both QoL dimensions of physical and mental functioning, while our findings demonstrated a reduction in only the physical dimension (total score) of QoL. Remarkably, the most differentiating aspect and the most disturbing QoL in the SOR-SMD group was found to be *Bodily pain*. This sub-scale refers to whether one has bodily pains and to which extent pain restricts household and work performance. Finding that the QoL of individuals with SMD is most affected by pain validates previous laboratory reports, as well as this study's results of more daily sensitivity to pain. Furthermore, since a QoL measure is an ecological one that encompasses aspects of daily functional status (Jason et al., 2011), this study demonstrates the importance of the pain aspect in understanding the SMD phenomenon and its interference in daily life. This may encourage practitioners to apply therapeutic interventions, targeting both sensory over-responsiveness and pain hypersensitivity in SMD subjects, in order to improve their QoL.

Most of the SMD knowledge is based on research in the pediatric population, though not considered a study limitation, we based part of the rational on these studies. The present study has two main limitations. Although SMD was found in 12.8% of the study sample, which is in line with the statistical probability reported in pediatric populations, the SMD group comprised only 32 individuals with SOR. Further, it is important to explore the association between sensory modulation and pain in a daily life context in SUR individuals as well. Moreover, although the study population varied in geographical and vocational variables, with approximately 50% consisting of university students, it is a convenience sample.

The finding that SMD over-responsivity is related to greater pain sensitivity in daily life, together with the increased probability of SMD in developmental disorders (autism and ADHD) warrants future studies. These studies may further explore pain perception in populations with developmental health conditions, testing whether pain may be an important factor shaping behavioral manifestations in daily life.

Acknowledgement

We thank Ben-Binyamin N., Kogan C., Marsha S., Reitman A., & Vataru T. for assisting with data collection.

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