Changes in sensory processing after anesthesia in toddlers

Johan M. Berghmans, Marten J. Poley, Jan van der Ende, Andre Rietman, Inge Glazemakers, Dirk Himpe, Frank C. Verhulst, Elisabeth Utens.

Minerva Anestesiol. 2018 Aug;84(8):919-928.

ABSTRACT

Background: Anesthesia and surgery may influence toddlers' sensory processing and consequently postoperative adjustment and behavior.

This is the first study to: 1. test pre- to postoperative changes in sensory processing after pediatric anesthesia using the validated Infant/Toddler-Sensory Profile for 7-36 months ($ITSP_{7\text{-}36}$); 2. identify putative predictors of these changes.

Methods: This prospective cohort study included 70 healthy boys (ASA I & II), aged 18-30 months, who underwent circumcision for religious reasons**.** Exclusion: boys with prior surgery and known developmental delay.

Primary outcome: Changes in sensory processing from the day of admission to day 14 postoperatively. The accompanying parent completed the $ITSP_{7\text{-}36}$. Putative predictors: 1. child's preoperative emotional/behavioral problems; 2. child's state anxiety at induction; 3. postoperative pain at home. All children received standardized anesthesia and pain management.

Results: For 45 boys, assessments were completed at both time points. Significant changes in sensory processing (mean $ITSP_{7\text{-}36}$ scores) were found on: low registration (47.5 to 49.8; $p = .015$), sensory sensitivity (45.2 to 48.0; $p = .011$), sensation avoiding (48.2 to 51.3; $p = .010$), low threshold (93.4 to 99.4; $p = .007$), auditory processing (39.3 to 43.3; $p = .000$) and tactile processing (53.9 to 58.4; $p = .002$). Higher scores on emotional/behavioral problems predicted changes on sensory processing.

Conclusions: Sensory processing of these toddlers had changed after anesthesia. Children with more pre-existent emotional/behavioral problems are more vulnerable to these changes.

Keywords: Anesthesiology, Anxiety, Infant, Postoperative Pain, Problem Behavior, Sensation

INTRODUCTION

Postoperative behavioral changes in preschool children are very common after surgery under anesthesia, with incidence rates ranging from 80.4% at day one postoperatively, to 32% four weeks after discharge and still 16% after three months[1-3]. The psychological impact of these changes cannot be ignored as in a minority of cases they may last even longer, from several months[1] to even more than a year[4]. Furthermore there are indications that young children are more vulnerable to such changes than are older children[1,4,5].

Research has shown a relationship between children's perioperative anxiety, emergence agitation and/or emergence delirium and postoperative pain on the one hand and postoperative behavioral changes on the other hand[1,3,6]. It may be that changes in sensory processing contribute to postoperative behavioral changes as well. Sensory processing encompasses the way toddlers perceive, modulate, integrate and self-regulate sensory information, and also how this sensory processing influences the toddlers arousal, attention, affect and action. In this way, a change in sensory processing might influence postoperative behavior changes, since sensory processing has an impact on the child's ability to learn and to show adaptive social functioning at home and e.g. to participate in play[7,8].

Furthermore, we postulate that several variables, which have been demonstrated to predict postoperative behavioral changes, may also influence young children's postoperative sensory processing. Previous studies showed that higher scores on preoperative emotional/behavioral problems (such as anxiety, depressive symptoms) are associated with higher levels of children's anxiety at induction[9,10]. We hypothesize that: 1) pre- to postoperative changes in sensory processing will occur after pediatric surgery under anesthesia; 2) that pre- and perioperative emotional/behavioral problems, especially anxiety during induction, and postoperative pain will change a child's sensory processing.

In this field of research, hardly any studies have focused on sensory processing in toddlers. The novelty of the present study lies in the identification of toddlers' changes in sensory processing after surgery under anesthesia and as such the impact on postoperative behavior, using a validated questionnaire that specifically targets this age group.

This study aims to: a. test pre- to postoperative changes in sensory processing, assessed by the $ITSP_{7-36}$, 14 days after a surgical day care procedure under anesthesia in children aged between 18 – 30 months; b. test whether changes in sensory processing are associated with: 1. the children's preoperative emotional/behavioral problems; 2. the children's state anxiety at induction; 3. postoperative pain at home.

MATERIALS AND METHODS

This prospective observational cohort study was conducted at the Queen Paola Children's Hospital in Antwerp, Belgium between April 2012 and April 2014, with approval from the Institutional Review Board (B009; OG031 E.C. approval N° 3952). It was part of a larger trial (www.trialregister.nl / NTR 3306), and was conducted in accordance with the Declaration of Helsinki, the APA ethical standards and reported following the STROBE statement for observational studies.

Inclusion criteria

Boys aged between 18-30 months, undergoing circumcision because of religious reasons in day care treatment; written informed consent; an American Society of Anesthesiologists (ASA) physical status I-II; no premedication (which is standard practice in our hospital); parents with a satisfactory written understanding of Dutch language; one parent present during induction.

Exclusion criteria

Known developmental delay, prior surgery under anesthesia.

Demographical/medical data

Collected on the day of admission by a research nurse. Socioeconomic status (SES) was categorized, by parental highest educational level into: 1. no education, elementary school; 2. secondary school; 3. higher education or university. Data were compared to Belgian population references[11].

Anesthesia procedure

All parents and children received standardized preoperative information. The anesthesia procedure was also standardized. In line with standard practice in our hospital, all inductions were performed by inhalation of sevoflurane 8 vol.% in 50% oxygen without nitrous oxide. A laryngeal mask was inserted and the child was assisted until breathing spontaneously. Anesthesia was maintained with sevoflurane 2.5 vol.%. Intraoperative pain management included: 1. a penile block with Levobupivacaine 2.5%; 2. opioids (pethidine 1.0 mg/kg IV); 3. a non-steroidal anti-inflammatory drug (NSAID) (ketorolac 0.5mg/kg IV) and 4. ondansetron (0.1 mg /kg) for post-operative nausea and vomiting (PONV) management. For in-hospital postoperative pain management each child received paracetamol IV (20 mg. kg^{-1}). At the end of surgery the inhalation agent was discontinued and the child was transferred to the Post Anesthesia Care Unit (PACU) and afterwards again to the ward were they stayed at least for 2 hours before discharge.

The parents received a written instruction for postoperative pain management at home stating that oral acetaminophen 60mg/kg divided in 4 doses should be given for 3 days. Adherence to this regimen on day 1 was recorded.

Assessment tools and assessment moments (Fig. 1)

Main outcome variable

The $\underline{ITSP_{7-36}}$[12] was developed to assess sensory processing skills of babies and toddlers between 7 and 36 months old. Sensory processing is defined as the capacity of the central nervous system for processing and modulating sensory input. The ITSP consists of 48 structured questions (response categories: 1 = almost always to 5 = almost never) and 2 open questions, resulting in a sensory processing summary covering 5 processing sections: 1. auditory (reaction to sound, noise, voices); 2. visual (reaction to anything that can be seen); 3. tactile (reaction to touching of the skin); 4. vestibular (reaction to movement); 5. oral sensory (reaction to touch, taste and smell).

In addition, 4 independent quadrant scores can be calculated: 1. weak registration (consciousness/ awareness to different sensory stimuli); 2. sensation seeking (seeking more intense sensory experiences); 3. sensory sensitivity (ability to notice sensory stimuli); 4. sensory avoiding (to counteract/avoid or control sensory stimuli). Finally a low threshold score is derived from the summation of quadrant 3 and 4.

Lower scores on the quadrant scores (i.e. scores below the reference range for healthy peers) indicate higher frequencies of these behaviors than in 'healthy' children, whereas higher scores indicate the opposite.

However, caution is warranted not to interpret ITSP concepts as problematic by definition; rather sensory processing should be regarded as a general concept describing a continuum of sensory experiences in children. Consequently when a child scores higher or lower *than others,* it simply means that the child shows behaviors (listed in the sections or quadrant groupings) more or less frequent than peers from the general population[13].

Test- retest reliability of the ITSP is acceptable for the quadrant scores (r = .74) and for sensory processing (r = .84), internal consistency ranges from acceptable to good (Cronbach's α = .70 to .86). In a systematic review of assessments of sensory processing the ITSP is being recommended because of sound psychometric properties and excellent content validity.[8] It was translated in Dutch[14].

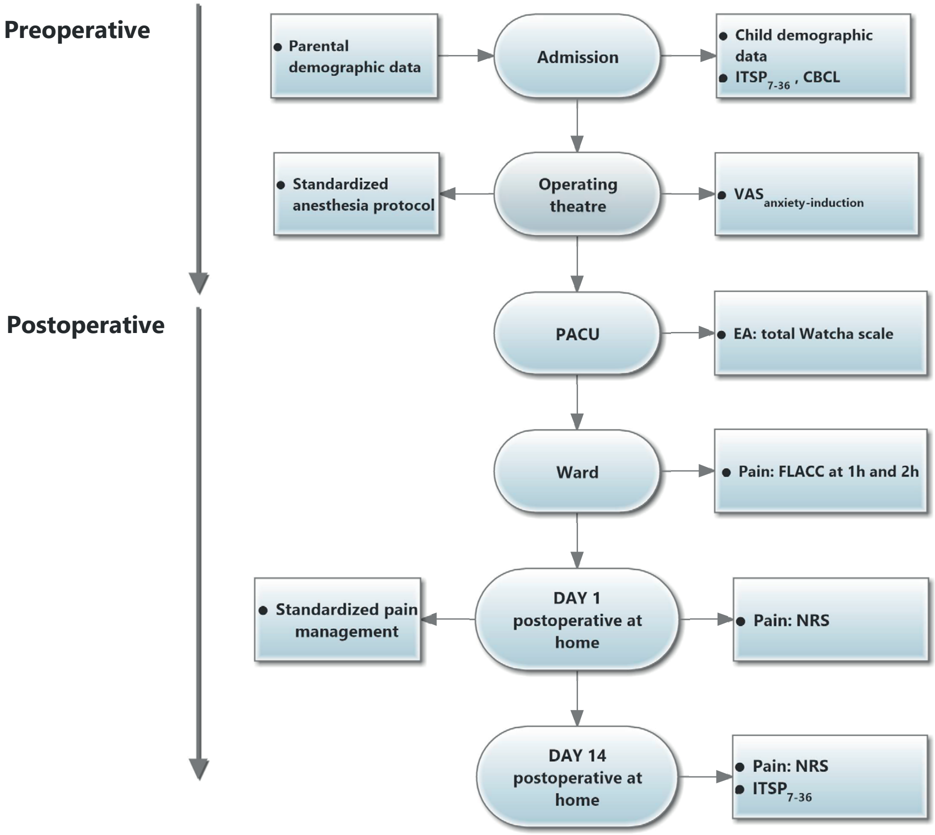
In this study the $ITPS_{7\text{-}36}$ was completed by the accompanying parent preoperatively at admission [T1] and postoperatively at day 14 [T14] (Fig. 1).

Predictor variables

The Child Behavior Checklist 1½-5 (CBCL/1½-5)[15], an internationally widely used and validated parent-report, was completed by the accompanying parent prior to surgery at [T1] to assess emotional/behavioral problems during the past 2 months (Fig. 1). It consists of 100 problem items (response-categories: 1. not true; 2. somewhat or sometimes true; 3. very true or often true). Summary scores on the Internalizing scale (Emotionally Reactive, Anxious/Depressed, Somatic Complaints, Withdrawn), Externalizing scale (Attention Problems and Aggressive Behavior), Sleep Problems and a Total Problems scale were computed. Higher scores indicate more problems. Good validity and reliability for the Dutch version have been reported[16].

The attending pediatric anesthesiologist completed a Visual Analogue Scale ($VAS_{anxiety\text{-}induction}$) to assess the child's anxiety level at induction. This scale consists of a 100 mm horizontal line, with the two ends representing the opposite, extreme limits 'absolutely no anxiety' and 'extreme anxiety', respectively. It has been used and was preliminarily validated for assessing a child's anxiety preoperatively[17].

Figure 1 ● Flowchart diagram of the different moments during assessment



$ITSP_{7\text{-}36}$, Infant/Toddler Sensory Profile 7-36 months as assessed by the accompanying mother or father
CBCL, Behavior Checklist 1½-5 as assessed by the accompanying mother or father
$VAS_{anxiety\text{-}anesthesiologist}$, Visual Analogue Scale anxiety at induction as assessed by the attending anesthesiologist
EA - Watcha, Emergence Agitation as assessed by a Post Anesthesia Care Unit (PACU) nurse
FLACC, Face Legs Activity, Cry and Consolability scale
NRS, Numerical Rating Scale

Emergence agitation (EA) was assessed postoperatively by a PACU nurse using the Watcha scale, which consists of 4 items: 1. calm; 2. crying, but consolable; 3. crying, not consolable; 4. agitated, kicking with arms and legs. A Watcha sum score was calculated, based on the scores at 5, 10, 15, and 20 minutes after awakening and a mean sum > 2 was considered to reflect the presence of EA. The scale is easy to use and has a high overall sensitivity and specificity[18].

The Face, Legs, Activity, Cry, Consolability (FLACC)[19] measures pain intensity. The FLACC has good interrater reliability and validity for use in the postoperative phase[19]. The FLACC was filled in 1 and 2 hours after surgery, on the ward by an independent nurse.

The child's postoperative pain at home was assessed with a Numerical Rating Scale (NRS)[20] At day 1 after discharge the research nurse called the parents to register the parents' rating of the child's pain (score-range: 0-10; question: how much pain did your child experience on average after surgery?). This was repeated at day 14, (score-range: 0-10; question: how much pain did your child experience on average during the past 14 days). NRS scores < 4 are considered to indicate no or mild pain; ≥ 4 to indicate moderate to serious pain[21].

Statistical analysis

A power calculation based on pre- to postoperative changes in sensory processing, as assessed 14 days after surgery, showed that, to detect a difference on the $ITSP_{7\text{-}36}$ low threshold score corresponding to an effect size of 0.5, a total sample size of 44 would be needed (GPOWER version 3.1.2) with a power of 0.90 and an alpha of 0.05.

All data are presented as mean ± standard deviation for continuous data, as percentages for categorical data or as median with IQR. Normal distribution was indicated by two characteristics (skewness and kurtosis) and was further confirmed/validated by Kolmogorov-Smirnov tests.

Paired Student's t tests were performed to analyze differences in $ITSP_{7\text{-}36}$ scores between [T1] and [T14] on: 1. sensory processing section scores; 2. quadrant scores; 3. low threshold score.

We first did a univariate linear regression analysis to estimate the associations between changes in sensory processing over time and three variables: 1) children's preoperative emotional/behavioral problems, 2) children's state anxiety at induction and 3) postoperative pain at home. The $ITSP_{7\text{-}36}$ scales that showed statistically significant differences over time (i.e., between T1 and T14) were used as dependent variables.

Next, multivariable linear regression (forced entry method) was used to analyze whether the changes in sensory processing (again restricted to those ITSP scales that showed significant change over time) could be explained by the predictor variables mentioned above. To avoid multicollinearity issues (assessed by variance inflation factors), predictor variables that correlated highly with other predictors were excluded from the regression analyses. Predictors were accepted into the model if their contribution to the model was statistically significant ($p < 0.05$). The standardized regression coefficients, which express the strength of each predictor in the regression equation, and explained variance (R^2) are presented. Linearity and homoscedasticity were tested by looking at the plots of standardized predicted values against the standardized residuals. Independence of residuals was checked with the Durbin-Watson statistic.

All analyses were performed with IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp. p-value of < 0.05 was considered statistically significant.

RESULTS

Of the 117 eligible children, 32 had to be excluded. The remaining 85 were invited to participate, 70 of whom accepted (response rate 82 %, Fig. 2). The children's mean age was 22.8 months (± 4.5 SD) (Table 1). For 25 (35.7%) children, data were missing at T14, because telephone contact was not possible or parents did not complete the $ITSP_{7\text{-}36}$, neither after a second telephone reminder. Thus for 45 children both pre- and postoperative data (T1 and T14) were available.

On the basis of the Watcha score, 22.7% of all 70 participants (n = 15; 4 missing values) could be categorized as having EA during the first 20 minutes after awakening (Table I).

Figure 2 Flowchart inclusion and exclusion of children

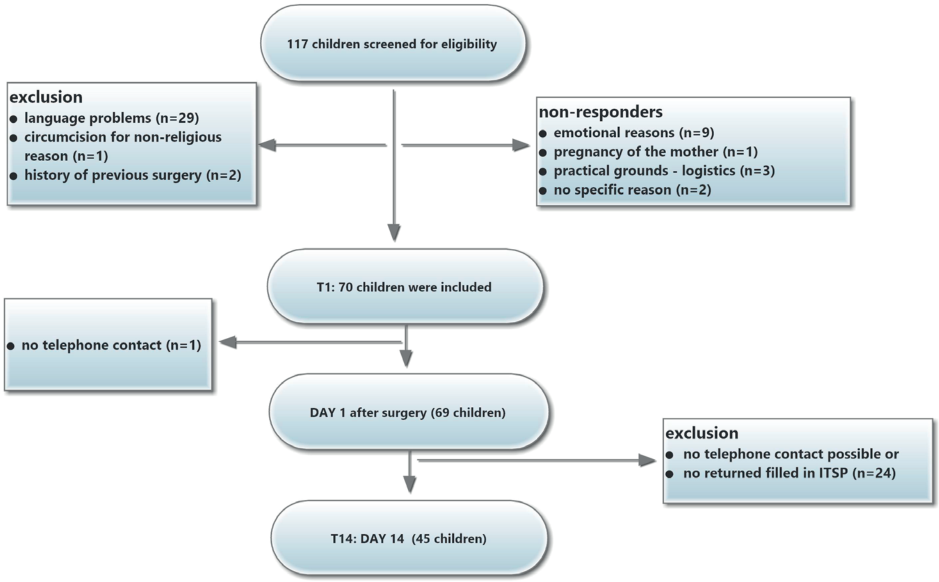


Table I Demographic and psychological assessment of the children and accompanying parent.

	Children with complete assessments at 2 time points (n = 45)	All children included (n = 70)
Children		
Age (months)	23 ± 4.0	22.8 ± 4.5
Weight	12.7 ± 2.3	12.8 ± 2.3
[a]ASA I	42 (93.3%)	63 (90%)
Born prematurely	4 (8.9%)	4 (5.7%)
Number of siblings ≥ 1	37 (82.2%)	58 (82.6%)
Prior hospitalizations	12 (26.7%)	19 (26.1%)
Nationality		
Belgium	37 (82.2%)	57 (81.4%)
other	8 (17.8%)	13 (18.6%)
[b]CBCL		
Internalizing problems	8.8 ± 7.3	8.7 ± 6.8
Externalizing problems	12.0 ± 6.4	11.6 ± 6.6
Total problems	31.9 ± 20.3	31.8 ± 18.9
[c]Anxiety at induction ($VAS_{anxiety\text{-}induction}$)	60.5 ± 29.2	65.5 ± 27.6
[d]Emergence delirium (Watcha score > 2)	10 (23.8%)	15 (22.7%)
(4 missing values)		
[e]In hospital postoperative pain (FLACC score)	0 (0 – 0)	0 (0 – 0)
[f]Pain at home (NRS)		
postoperative day 1	4 (0 – 6)	3 (2 – 6)
postoperative day 14	3 (0 – 7)	
Prescribed pain medication adherence	23 (51.1%)	40 (57.1%)
Parents		
Gender of accompanying parent (% male)	30 (66.7%)	44 (62.9%)
[g]Highest educational level	11 (24.4%)	17 (24.3%)
	28 (62.2%)	42 (60%)
	6 (13.3%)	11 (15.7%)

Data are expressed as mean ± SD or as median with IQR or as number (%). [a]ASA, American Society of Anesthesiologists; [b]CBCL, Child Behavior Checklist 1½-5 (Internalizing, Externalizing and Total Problems); [c]Child Anxiety at induction: $VAS_{anxiety\text{-}induction}$, Visual Analogue Scale anxiety; [d]Emergence delirium – total Watcha score was obtained by summing the scores at 5 min, 10 min, 15 min and 20 min after awakening; [e]In hospital postoperative pain: FLACC = Face, Legs, Activity, Cry, Consolability scale, sum score (1 hour + 2 hour) ; [f]Pain at home: NRS = Numeric Rating Scale at postoperative day 1 and day 14; [g]Highest educational level: 1. no education, elementary school; 2. secondary school; 3. higher education or university - [reference values for the Belgian population: level 1 = 13.9%; level 2 = 56.2%; level 3 = 29.9%].

Postoperative pain scores

One child had been assigned a score > 3 on the FLACC scale (n = 70). Parents of 49.3% (n = 35) of the children considered the child's postoperative pain moderate to serious at day 1, as assessed with the NRS. At day 14, 48.9% (n = 22) of parents reported that the overall pain experienced the past 14 days by their child was moderate to serious. Prescribed pain medication at day 1 at home was given conform instructions by 57.1% (n = 40) of parents.

The parent who accompanied the child during induction of anesthesia was the father in almost two third (62.9%) of the cases.

Pre- postoperative changes sensory processing

Paired Student's t tests showed statistically significant differences between $ITSP_{7\text{-}36}$ mean scores on T1 and T14 for the sections auditory and tactile processing, indicating that children postoperatively have significantly sharper, more sensitive, strong and alert auditory and tactile information processes (Table II). On the 'visual processing' and 'vestibular processing' sections of the $ITSP_{7\text{-}36}$, the children's scores increased slightly over time, but these changes were not statistically significant. Except for the sensation seeking quadrant, all quadrant scores increased significantly over time.

Table II Pre- to postoperative changes on the Infant/Toddler Sensory Profile

	T1 (n = 45)	**T 14** (n =45)	**mean DIFF**	**P value**	**ES**
Sensory processing section					
Auditory processing	39.3 (± 4.9)	43.3 (± 4.5)	+4.0 [2.5, 5.7]	.000**	0.77
Visual processing	22.0 (± 4.2)	22.4 (± 3.9)	+.36 [.9, 1.6]	.57	
Tactile processing	53.9 (± 9.0)	58.4 (± 7.8)	+4.5 [1.8, 7.0]	.002**	0.50
Vestibular processing	20.1 (± 3.5)	20.3 (± 3.6)	+.2 [.8, 1.1]	.75	
Oral sensory processing	29.2 (± 4.3)	28.0 (± 4.2)	-1.2 [-.5, 2.8]	.18	
Quadrant grid					
Quadrant 1 - Low registration	47.5 (± 6.4)	49.8 (± 3.6)	+2.3 [.5, 4.1*	.015*	0.38
Quadrant 2 - Sensation seeking	35.9 (± 8.3)	36.2 (± 8.0)	+.3 [-2.1, 2.7]	.82	
Quadrant 3 - Sensory sensitivity	45.2 (± 7.1)	48.0 (± 5.8)	+2.8 [.7, 4,9]	.011*	0.40
Quadrant 4 – Sensation avoiding	48.2 (± 7.2)	51.3 (± 7.4)	+3.1 [.8, 5.5]	.010*	0.40
Low Threshold (combined quadrant 3+4 score)	93.4 (± 13.5)	99.4 (± 12.4)	+6.0 [1.7, 10.1]	.007**	0.42

Data are expressed as mean (± SD) or as mean [95% CI]; T1 = baseline measure; T14 = measure at day 14 postoperative; mean DIFF: mean difference. Paired T- tests between quadrant scores at T1 and T14 and sensory processing section at T1 and T14. *P < 0.05; **P < 0.01 as determined with a paired T- test. ES: effect size (Cohen's d): 0.2 (small); 0.5 (medium); 0.8 (large) has been calculated using the formula: d = mean DIFF/SD.

Results of the univariate regression analyses showed that the CBCL Total Problems score and the CBCL Internalizing Problems score were statistically significant predictors of changes in sensory processing over time (standardized regression coefficients between .29 and .43). This holds for all ITSP sensory processing sections and all quadrant grids, except for the association between Internalizing Problems and auditory processing (Table III). There were no statistically significant associations between CBCL Externalizing Problems, the child's anxiety at induction, and postoperative pain at home, and changes in ITSP scores.

Table III Pre- to postoperative changes on quadrant and sensory processing sections of the Infant Toddler/Sensory Profile - univariate regression models

	ΔaudP	**ΔtactP**	**ΔQ. 1**	**ΔQ. 3**	**ΔQ. 4**	**ΔQ.LT**
Internalizing problems	.21 (.16)	.37 (.013)*	.33 (.028)*	.43 (.003)**	.29 (.046)*	.38 (.01)*
Externalizing problems	.24 (.119)	.28 (.061)	.28 (.065)	.25 (.097)	.19 (.215)	.23 (.126)
Total problems	.29 (.047)*	.38 (.011)*	.39 (.008)**	.43 (.003)**	.30 (.046)*	.38 (.01)*
$VAS_{anxiety\text{-}induction}$	.06 (.703)	.24 (.107)	-.023 (.88)	.23 (.122)	.16 (.286)	.21 (.169)
NRS postoperative day 1	.09 (.567)	.11 (.477)	.06 (.681)	.09 (.577)	.00 (.987)	.05 (.773)
NRS postoperative day 14	.04 (.777)	-.04 (.787)	-.23 (.146)	.11 (.500)	-.06 (.701)	.02 (.908)

Data are expressed as: standardized regression coefficients (P value); *P < 0.05; **P < 0.01.
Dependent variables from the Infant/Toddler Sensory Profile (ITSP) : Δaudp = Difference Auditory processing = [Auditory processing T14] – [Auditory processing T1]; Δtactp = Difference Tactile processing = [Tactile processing T14] – [Tactile processing T1]; ΔQ. 1 = Difference quadrant 1 = [quadrant 1 T14] – [quadrant 1 T1]; ΔQ. 3 = Difference quadrant 3 = [quadrant 3 T14] – [quadrant 3 T1]; ΔQ. 4 = Difference quadrant 4 = [quadrant 4 T14] – [quadrant 4 T1]; ΔQ.LT = Difference low threshold = [quadrant 3+4 T14] – [quadrant 3+4 T1];.
Independent variables: Child Behavior Checklist 1½-5 as assessed by the accompanying mother or father, Internalizing, Externalizing and Total problems; $VAS_{anxiety\text{-}induction}$: Child anxiety at induction = Visual Analogue Scale anxiety at induction; NRS = Numeric Rating Scale at postoperative day 1 and day 14.

In the multivariate regression analyses, the NRS pain score at day 1, the CBCL Internalizing problems score and the CBCL Externalizing problems score were left out, for reasons of multicollinearity. So, the following predictor variables were considered: 1) CBCL Total problems score; 2) anxiety at induction, and 3) postoperative assessment of pain during the past 14 days. The analyses revealed that the changes over time on the ITSP were related to higher scores on preoperative CBCL total problems score (Table IV). Anxiety at induction and – with one expection - postoperative pain at 2 weeks did not make a statistically significant contribution to explaining the changes in sensory processing. Between 9% and 25% of the variance of the ITSP dimensions was explained by preoperative emotional/behavioral problems (and postoperative pain).

Table IV Results of the multivariable regression models

	ΔaudP	ΔtactP	ΔQ. 1	ΔQ. 3	ΔQ. 4	ΔQ.LT
CBCL – total problems	.298(.047)*	.377(.011)*	.459(.002)**	.427(.003)**	.299(.046)*	.382(.010)*
Anxiety at induction ($VAS_{anesthesiologist}$)						
Postoperative pain (NRS day 14)			-.314(.03)*			
Variance explained (R^2)	.089(.047)*	.142(.011)*	.254(.003)**	.182(.003)**	.089(.046)*	.146(.010)*

Data are expressed by: standardized regression coefficient (P value); model R^2 (P value); P value: *P < 0.05.; **P < 0.01. Independent variables: 1.CBCL – preoperative Total problems, Child Behavior Checklist 1½-5; 2. The child's anxiety at induction with a Visual Analogue Scale - $VAS_{anesthesiologist}$; 3. Postoperative pain scores by a Numerical Rating Scale (NRS) at day 14. **Dependent variables from the Infant/Toddler Sensory Profile ($ITSP_{7-36}$):** Δaudp = Difference Auditory processing = [Auditory processing T14] – [Auditory processing T1]; Δtactp = Difference Tactile processing = [Tactile processing T14] – [Tactile processing T1]; ΔQ. 1 = Difference quadrant 1 = [quadrant 1 T14] – [quadrant 1 T1]; ΔQ. 3 = Difference quadrant 3 = [quadrant 3 T14] – [quadrant 3 T1]; ΔQ. 4 = Difference quadrant 4 = [quadrant 4 T14] – [quadrant 4 T1]; ΔQ.LT = Difference low threshold = [quadrant 3+4 T14] – [quadrant 3+4 T1].

DISCUSSION

The present study found evidence for significant pre- to postoperative changes in sensory processing of children undergoing circumcision. Analysis showed significant changes on different quadrants (low registration, sensory sensitivity, sensation avoiding and low threshold) and on auditory and tactile processing two weeks after surgery. Postoperatively less distinct behaviors were seen in response to auditory and tactile stimuli. From a clinical point of view these sensory processing changes can have a considerable psychological impact by influencing the toddlers' daily functioning and as such are clinically relevant. Preoperative emotional/behavioral problems significantly predicted pre- to postoperative changes in sensory processing.

The higher postoperative scores on low registration, sensory sensitivity, sensation avoiding, and low threshold indicate that, compared to their pre-operative situation, in some situations the children *miss less* information. Otherwise stated: they *detect more information* (i.e. show less behavior associated with 'low registration': e.g. touch or loud talk is not needed to get the child's attention). In other situations however, they *detect less* (i.e. show less behavior reflecting 'sensory sensitivity', e.g. do not startle from noise), and are *less bothered by input* (i.e. show less 'sensation avoiding', e.g. do not resist cuddling). These divergent findings can be explained by the fact that the quadrants cover different domains of sensory processing and behaviours belonging to these diverging domains, whereas they all fall under the overarching umbrella of the concept 'sensory processing'. In other words, generally speaking, children may for instance react strongly to auditory stimuli (by avoiding), and at the same time react less strongly to motion stimuli. And furthermore, a child may react differently to the same stimuli in different situations (e.g. an alarming ringtone while playing at home versus while lying in bed in-hospital).

Overall, our findings on the pre- to postoperative changes in sensory processing indicate that postoperatively after circumcision, in most situations, these boys after having undergone circumcision under anesthesia react less strongly to sensory input. Such behaviour could be interpreted as withdrawn or passive. However, these sensory processing changes (reflected by higher scores on the ITSP) do not necessarily imply more problematic behavior. When children are less conscious or less aware of sensory stimuli, they may be less sensitive and less alert to information. This could have been the case for the children in this study, since quadrant scores on sensation sensitivity, sensation avoiding, and the low threshold score were higher in the post-operative period. These sensory processing changes (as reflected by higher scores) could give rise to under-responsive behavior which could be explained through habituation after the surgical experience.

Clinical relevance. The findings mentioned above are of *clinical relevance*, since changes in sensory processing (e.g. less alert detection of auditory/visual information) can influence the child's ability to show adaptive social functioning at home. The fact that toddlers can be under-responsive (more withdrawn, more passive, less sensitive and alert) after surgery, constitutes important information which a clinician should convey to parents. Importantly, some children seem more vulnerable to these sensory processing changes, especially children with pre-existent preoperative emotional/behavioral problems.

When interpreting the results of this study, it needs to be kept in mind that this is a rather unexplored field of study using the ITSP and that the surgery was minor, elective and performed voluntarily for religious reasons (which may have resulted in informant bias, perhaps underestimating children's behavioral changes). Despite the surgery being 'minor', we nonetheless found significant changes in sensory processing. Therefore we think that our results are to be considered as a first signal that changes in sensory processing may occur, even after mild anesthesia. To what extent changes in sensory processing will occur after more serious or repetitive surgeries, with more and longer anesthesia and whether these changes persist into the long-term is a worthy area of investigation for future studies.

We found that the changes in the ITSP scores were associated with preexisting emotional/behavioral problems. This could be explained by the fact that children with more emotional/behavioral problems (especially Internalizing; emotionally reactive, anxious/

depressed, somatic complaints, withdrawn) have more behavior inhibition[22]. These children tend to be more calm, withdrawn and in general react less strongly to different experiences. This is consistent with the findings of Fortier *et al,*[23] who reported that individual child emotional/behavioral problems as assessed with the CBCL were predictive for changes in postoperative behavior.

Although pain has been identified as a strong risk factor of postoperative problematic behavior,[3,5] in this study no clear associations were found between pain and pre- to postoperative changes in sensory processing. This may be partly explained by the nature of pain instrument used in this study (i.e., the NRS). This short instrument was chosen to minimize the burden to the parents. However, it is a global rating scale, which may have influenced the sensitivity to detect changes. In hospital the children were assigned very low pain scores. However at home almost 50% of the children were perceived to have moderate to serious pain, both at day 1 and day 14 after discharge. Nevertheless, 40% of the parents did not adhere to the prescribed medication regimen. Others have reported similar findings[24,25]. Moreover, the religious significance of male circumcision may have contributed to a different parental attitude concerning pain medication. A study indeed found that parents were likely to consider pain as something that is inseparably linked to Calvinistic values[26] The cultural background might explain the relatively high proportion of fathers present at induction and this may have influenced the ratings by parents.

Besides pain, also the child's state anxiety has been reported as a factor explaining postoperative behavioral changes[4,6]. Overall, in this study, the regression coefficients did not reach the level of statistical significance. This may be partly explained by the fact that measuring state anxiety at induction in very young children is very difficult[17].

Strengths and limitations

Strengths: This study is innovative since it is the first investigating: a) pre- to postoperative changes in sensory processing in a *homogeneous* group of toddlers, using a well-validated questionnaire, the ITSP, and b) preoperative children's emotional/behavioral problems as a significant predictor, using the internationally well-known CBCL.

Limitations

This was a single center study with drop-outs at day 14 postoperatively. To what extent selection bias may have influenced our results is unknown. Furthermore, it seems that parents with low education were overrepresented compared to national statistics for Belgium (24.4% in this study vs 13.9 % the general population)[11]. The children, boys only, underwent minor, elective surgery (circumcision for religious reasons), these factors may have affected our results. Furthermore, parents completed both the CBCL and the $ITSP_{6\text{-}36}$ which may have affected the associations – this phenomenon where the same respondent completes several measures is known as *common method variance*[27]. It would be desirable if future studies would use a multi-informant approach (both parents as independent informants).

CONCLUSIONS

Our findings demonstrate that following surgery boys (18-30 months) reacted less sensitively, less strong (less alert) to sensory input, suggesting higher thresholds and more habituation. Future research should address: how long these changes in sensory processing last, how they affect postoperative behavior in toddlers, whether larger changes in sensory processing occur after more serious surgeries requiring longer anesthesia, and whether there are gender differences in sensory processing changes after pediatric surgery.

Preoperative emotional/behavioral problems predicted pre-to-postoperative changes in sensory processing. Anesthesiologists should be aware that children with current emotional/behavioral problems are more vulnerable to postoperative changes in sensory processing.

REFERENCES

1. Stargatt R, Davidson AJ, Huang GH, et al. A cohort study of the incidence and risk factors for negative behavior changes in children after general anesthesia. Pediatr Anesth 2006; 16: 846-59.
2. Fortier MA, Del Rosario AM, Rosenbaum A, et al. Beyond pain: predictors of postoperative maladaptive behavior change in children. Pediatr Anesth 2010; 20: 445-53.
3. Power NM, Howard RF, Wade AM, et al. Pain and behaviour changes in children following surgery. Arch Dis Child 2012; 97: 879-84.
4. Kain ZN, Mayes LC, O'Connor TZ, et al. Preoperative anxiety in children. Predictors and outcomes. Arch Pediatr Adolesc Med 1996; 150: 1238-45.
5. Karling M, Stenlund H, Hagglof B. Child behaviour after anaesthesia: associated risk factors. Acta Paediatr 2007; 96: 740-7.
6. Kain ZN, Caldwell-Andrews AA, Maranets I, et al. Preoperative anxiety and emergence delirium and postoperative maladaptive behaviors. Anesth Analg 2004; 99: 1648-54.
7. Dunn W, Little L, Dean E, et al. The State of the Science on Sensory Factors and Their Impact on Daily Life for Children: A Scoping Review. Ocupational Therapy Journal of resaerch 2016; 36: 3S-26S.
8. Eeles AL, Spittle AJ, Anderson PJ, et al. Assessments of sensory processing in infants: a systematic review. Dev Med Child Neurol 2013; 55: 314-26.
9. Berghmans JM, Poley M, Weber F, et al. Does the Child Behavior Checklist predict levels of preoperative anxiety at anesthetic induction and postoperative emergence delirium? A prospective cohort study. Minerva Anestesiol 2015; 81: 145-56.
10. Fortier MA, Martin SR, Chorney JM, et al. Preoperative anxiety in adolescents undergoing surgery: a pilot study. Pediatr Anesth 2011; 21: 969-73.
11. http://statbel.fgov.be/nl/statistieken/cijfers/arbeid_leven/opleiding/niveau/: 2017.
12. Dunn W, Daniels DB. Initial Development of the Infant/Toddler Sensory Profile. Journal of Early Intervention 2002; 25: 27-41.
13. Understanding Sensory Processing: An Update/Updating Our Understanding of Sensory Processing. The Psychological Corporation Harcourt, 2003 http://images.pearsonclinical.com/images/pdf/understandingsensoryprocessing.pdf: 2017.
14. Winnie Dunn, André Rietman. Handleiding: Infant/Toddler Sensory-NL, Baby's en Peuters (0 T/M 2 jaar), Harcourt 2006.
15. Achenbach TM, Rescorla, LA. Manual for the ASEBA school-age forms and profiles. Burlington, VT: University of Vermont, Research Center for Children, Youth and Families. 2001.
16. Verhulst FC, Van der Ende J, Koot HM. Handleiding voor de CBCL/4-18. Rotterdam, Department of Child and Adolescent Psychiatry, Sophia Children's Hospital, Erasmus University Rotterdam, 1996.
17. Berghmans JM, Poley MJ, van der Ende J, et al. A Visual Analog Scale to assess anxiety in children during anesthesia induction (VAS-I): Results supporting its validity in a sample of day care surgery patients. Pediatr Anesth 2017; 27: 955-961.
18. Bajwa SA, Costi D, Cyna AM: A comparison of emergence delirium scales following general anesthesia in children. Pediatr Anesth 2010; 20: 704-11.
19. Merkel SI, Voepel-Lewis T, Shayevitz JR, et al: The FLACC: a behavioral scale for scoring postoperative pain in young children. Pediatr Nurs 1997; 23: 293-7.
20. von Baeyer CL, Spagrud LJ: Systematic review of observational (behavioral) measures of pain for children and adolescents aged 3 to 18 years. Pain 2007; 127: 140-50.

21. Gerbershagen HJ, Rothaug J, Kalkman CJ, et al: Determination of moderate-to-severe postoperative pain on the numeric rating scale: a cut-off point analysis applying four different methods. Br J Anaesth 2011; 107: 619-26.
22. Biederman J, Rosenbaum JF, Hirshfeld DR, et al. Psychiatric correlates of behavioral inhibition in young children of parents with and without psychiatric disorders. Arch Gen Psychiatry 1990; 47: 21-6.
23. Fortier MA, Del Rosario AM, Rosenbaum A, et al. Beyond pain: predictors of postoperative maladaptive behavior change in children. Pediatr Anesth 2010; 20:445-453.
24. Dorkham MC, Chalkiadis GA, von Ungern Sternberg BS, et al. Effective postoperative pain management in children after ambulatory surgery, with a focus on tonsillectomy: barriers and possible solutions. Pediatr Anesth 2014; 24: 239-48.
25. Rony RY, Fortier MA, Chorney JM, et al. Parental postoperative pain management: attitudes, assessment, and management. Pediatrics 2010; 125: e1372-8.
26. Kankkunen P, Vehvilainen-Julkunen K, Pietila AM, et al. Parents' perceptions and use of analgesics at home after children's day surgery. Pediatr Anesth 2003; 13: 132-40.
27. Collishaw S, Goodman R, Ford T, et al. How far are associations between child, family and community factors and child psychopathology informant-specific and informant-general? J Child Psychol Psychiatry 2009; 50: 571-80.