CASE REPORT

Preoperative therapeutic neuroscience education for lumbar radiculopathy: a single-case fMRI report

Adriaan Louw, PT, PhD1, Emilio J. Puentedura, PT, DPT, PhD2, Ina Diener, PT, PhD3, and Randal R. Peoples, MS, MD4

1International Spine and Pain Institute, Story City, IA, USA, 2Department of Physical Therapy, School of Allied Health Sciences, University of Nevada, Las Vegas, Las Vegas, NV, USA, 3Department of Physical Therapy, Stellenbosch University, Stellenbosch, South Africa, and 4Department of Neurosurgery, St Rose Neurosurgery Clinic, Stanford University, Henderson, NV, USA

Abstract

Therapeutic neuroscience education (TNE) has been shown to be effective in the treatment of mainly chronic musculoskeletal pain conditions. This case study aims to describe the changes in brain activation on functional magnetic resonance imaging (fMRI) scanning, before and after the application of a newly-designed preoperative TNE program. A 30-year-old female with a current acute episode of low back pain (LBP) and radiculopathy participated in a single preoperative TNE session. She completed pre- and post-education measures including visual analog scale (VAS) for LBP and leg pain; Oswestry Disability Index (ODI); Fear Avoidance Beliefs Questionnaire (FABQ); Pain Catastrophizing Scale (PCS) and a series of Likert-scale questions regarding beliefs and attitudes to lumbar surgery (LS). After a 30-minute TNE session, ODI decreased by 10%, PCS decreased by 10 points and her beliefs and attitudes shifted positively regarding LS. Immediately following TNE straight leg raise increased by 7° and forward flexion by 8 cm. fMRI testing following TNE revealed three marked differences compared to pre-education scanning: (1) deactivation of the periaqueductal gray area; (2) deactivation of the cerebellum; and (3) increased activation of the motor cortex. The immediate positive fMRI, psychometric and physical movement changes may indicate a cortical mechanism of TNE for patients scheduled for LS.

Introduction

Research into educational strategies for patients with chronic low back pain (CLBP) shows an increased use of therapeutic neuroscience education (TNE) (Louw, Diener, Butler, and Puentedura, 2011; Moseley, 2003a, 2004, 2005; Moseley, Hodges, and Nicholas, 2004). TNE differs from traditional educational strategies which focus on anatomy, pathoanatomy or biomechanics of anatomical structures within the lower back to explain pain to a patient; rather focusing with greater emphasis on the neurophysiology, neurobiology, and processing of a patient’s pain experience by the central nervous system and brain (Meeus et al, 2010; Moseley, 2005; Ryan, Gray, Newton, and Granat, 2010). Patients are interested in knowing more about their pain and disability by helping patients’ gain an increased understanding of the biological process underpinning their pain state (Ryan, Gray, Newton, and Granat, 2010). A recent systematic review confirmed TNE as an effective intervention in chronic musculoskeletal pain conditions (Louw, Diener, Butler, and Puentedura, 2011).

TNE is an education intervention which aims to reduce pain and disability by helping patients’ gain an increased understanding of the pain experience (Moseley, 2005; Moseley, Hodges, and Nicholas, 2004; Puentedura, Brooksby, Wallmann, and Landers, 2009; Ryan, Gray, Newton, and Granat, 2010; Van Oosterwijck et al, 2011; Zimney, Louw, and Puentedura, 2014). Furthermore, TNE has been shown to lead to increased pain thresholds during physical tasks, improved outcomes of therapeutic exercises, and significant reduction in widespread brain activity characteristic of a pain experience (Moseley, 2005; Moseley, Hodges, and Nicholas, 2004; Puentedura, Brooksby, Wallmann, and Landers, 2010). Additionally, it has also been shown that patients with persistent pain may become fixated on words and descriptors of pain (Wilson, Williams, and Butler, 2009). The pain neuromatrix, originally described by Melzack (1990) and subsequently supported by imaging studies (Flor, 2000, 2003;...
Flor, Braun, Elbert, and Birbaumer, 1997; Moseley, 2005) provides a framework for the hypothesis that terminology describing a patient’s pain experience may in fact produce a heightened central nervous system response, including brain activation. In central sensitization, the central nervous system (spinal cord, brain stem, cerebral hemispheres) displays a heightened response to input, such as sensory or verbal information (Woolf, 2007). The pain neuromatrix and ultimately the patient’s pain experience, however, is influenced by various neighboring maps, including beliefs, threats, experiences and more (Puentedura and Louw, 2012). In line with this, it is believed that provocative words posing a threat may result in induced fear and anxiety, which has been correlated to increased pain experiences (Fritz et al, 2004; Klaber-Moffett, Green, and Jackson, 2005; Woolf, 2007).

It is well established that issues surrounding the surgical environment (i.e. anesthesia, uncertainty, unknowns, sounds, and personnel) are associated with increased stress and anxiety (Galaal, Deane, Sangal, and Lopes, 2007; Rosen, Svensson, and Nilsson, 2008; Salzwedel et al, 2008) and several studies have shown that increased anxiety in the preoperative period is associated with increased postoperative pain (Muglali and Komierik, 2008; O’Connor-Von, 2008; Rice, Glasper, Keeton, and Spargo, 2008; Rosen, Svensson, and Nilsson, 2008; Salzwedel et al, 2008; Wang, Shen, Lu, and Yang, 2008). Additionally, several studies have shown that pain, especially level of pain intensity and unexpected high levels of pain after surgery, is a critical issue within orthopedic surgery (Niskanen and Strandberg, 2005; Parker, Handoll, and Griffiths, 2004; Pitimana-aree et al, 2005; Sinatra, Torres, and Bustos, 2002; Wulf et al, 1999)). Preoperative education is a strategy designed to decrease postoperative pain, complications and disability (Oshodi, 2007a; Oshodi, 2007b). To date, only a handful of studies have been conducted on the outcome of preoperative education for lumbar surgery, and those with a focus on procedural information and informed consent have demonstrated limited benefit for post-surgical outcomes (Douglas, Mann, and Hodge, 1998; Johansson et al, 2005; Krupp, Spanehl, Laubach, and Seifert, 2000; LaMontagne, Hepworth, Salisbury, and Cohen, 2003; Walters and Coad, 2006). This may be because most of the education programs used in orthopedic patient populations have utilized anatomical and biomechanical models for addressing pain (Brox et al, 2008; Butler and Moseley, 2003; Maier-Riehle and Harter, 2001; Moseley, 2004) which not only show limited efficacy (Brox et al, 2008; Butler and Moseley, 2003; Koes, van Tulder, van der Windt, and Bouter, 1994; Maier-Riehle and Harter, 2001; Waddell, 2004) but may even increase patient fears, anxiety and stress, thus negatively impacting outcomes (Hirsch and Liebert, 1998; Maier-Riehle and Harter, 2001; Nachemson, 1992; Poiradeau et al, 2006). A recent survey of preoperative education utilized by US spine surgeons (Louw, Butler, Diener, and Puentedura, 2013) indicated that surgeons readily utilize such orthopedic-based education models, with 97% of the surveyed surgeons, indicating the use of a spine and disk model to explain the mechanism behind the patient’s pain as well as proposed mechanism behind decompression surgery relieving radicular pain. This “use of a disk model” constitutes the biomedical (anatomical/pathoanatomical) model proposed as the traditional model of teaching people about pain, in contrast to TNE (Louw, Diener, Butler, and Puentedura, 2011; Moseley, Hodges, and Nicholas, 2004).

In lieu of the high levels of fear and anxiety prior to lumbar surgery, the limited effect of biomedical and procedural education prior to surgery, and the evidence for TNE, a preoperative neuroscience educational tool (PNET) was recently developed for pre-operative education of lumbar radiculopathy patients (Louw, Butler, Diener, and Puentedura, 2013). The PNET was based on various studies regarding pain science (the latest research on the biological and physiological mechanisms involved in a pain experience), surgery and various forms of patient education (Louw, Butler, Diener, and Puentedura, 2012, 2013; Louw, Diener, Butler, and Puentedura, 2011; Louw, Louw, and Crous, 2009). The PNET was used in a multi-center RCT and demonstrated immediate post-education positive effects on fear, catastrophization, attitudes and beliefs regarding lumbar surgery as well as range of motion (ROM) including straight leg raise (SLR) and active trunk forward flexion (Louw, Butler, Diener, and Puentedura, 2013). Considering the immediate positive changes to ROM, psychometric measures of pain, as well as attitudes and beliefs regarding lumbar surgery in the absence of a physical intervention (manual therapy or exercise) it is postulated that the immediate changes may in fact be due to a change in the construction of a patient’s pain neuromatrix.

The purpose of this single-case study was to have a patient scheduled for lumbar radiculopathy surgery to undergo a functional MRI (fMRI) scan before and immediately after the application of the PNET. The scans were taken during the performance of a painful task and we wanted to determine if there would be any immediate changes in brain activation after the provision of PNET. We also wanted to determine if any observed changes in brain activation during a painful task might be associated with changes in self-reported beliefs and attitudes regarding surgery, psychometric measurements and ROM.

Case description

The patient

The patient was a well-nourished, healthy 30-year-old female high-level professional dancer who provided consent for the study, including undergoing fMRI while performing a painful task. The patient had a 4-year history of chronic recurrent LBP, with a current acute episode of 3 months. The patient could not recall a specific injury or accident, and related her symptoms to her work as a professional dancer and the repetitive strain on her back. Her symptoms had been treated conservatively with physical therapy (manual therapy, exercise and modalities), medication and modified or decreased activity. The patient had undergone magnetic resonance imaging (MRI) studies of her lumbar spine on three separate occasions with each revealing an L5/S1 disk bulge (patient unable to recall dates). The most recent scan (3 months previously) demonstrated a marked herniated L5/S1 disk; central and left towards the nerve root (Figure 1).

Clinically, the patient presented with no visible distress, demonstrated normal gait and no visible abnormalities with functional tasks such as sitting, transfers to and from sit-to-stand, taking her shoes off and putting on a gown needed for the fMRI procedure. On the day of the study, the patient reported vague, constant, non-variable LBP across the back (left more than right), spanning the L2-L5 spinal levels, and radiating pain into both buttocks and upper thighs (anterior). The patient denied any neurological symptoms, including sensory symptoms or muscle weakness. Her neurosurgeon, who was present, reported decreased motor power of great toe extension on the left foot, with manual muscle testing.

Intake forms

Following a review of systems, the patient completed various intake forms: demographics questionnaire; fear avoidance beliefs questionnaire (FABQ) (Waddell et al, 1993); pain catastrophization scale (PCS) (Zimney, Louw, and Puentedura, 2014); Oswestry disability index (ODI) (Deyo et al, 1998; Fritz and Irrgang, 2001); visual analogue scale (VAS) for LBP and leg pain.
Cleland (2003a; Moseley, 2005); pain neurophysiology questionnaire (Moseley, 2003b); and a series of Likert-scale questions on her beliefs and attitudes regarding lumbar surgery as it related to her LBP and leg pain (Louw, Louw, and Crous, 2009).

The intake data portrayed a patient presenting with moderate LBP, left leg pain, high fear levels associated with physical activity and work, a high level of pain catastrophization, limited knowledge of pain and various beliefs regarding the pending lumbar surgery (Table 1).

### Physical Measurements

Formal physical examination consisted of 3 tests pertaining to the study. These tests were performed in a manner as to minimally increase her acute LBP and radiculopathy. Formal tests included: (1) active trunk forward flexion, measured from the longest finger on the dominant hand to the floor (Figure 1) (Moseley, 2004; Moseley, Hodges, and Nicholas, 2004; Zimney, Louw, and Puenteuda, 2014); (2) straight leg raise (SLR), measured with an inclinometer placed on the tibial plateau 5 cm distal to the inferior border of the patella on the affected leg (left) (Figure 2) (Moseley, 2004; Moseley, Hodges, and Nicholas, 2004; Zimney, Louw, and Puenteuda, 2014); and (3) three pressure pain threshold (PPT) measures (average of three measurements used for results), using a pressure-pain algometer at the web space of the dominant hand, adjacent to the L3 spinous process on the affected side (left) and the posterior knee of the affected leg (left) (JTech™) (Fernandez-de-las-Penas et al, 2009, 2010; Mendez-Sanchez et al, 2011). Given the high levels of fear and potential provocative nature of forward flexion with herniated disks, active forward flexion was only performed once. Additionally, given the patient’s significant flexibility as a dancer, she stood on a stool (20 cm off the floor) to ensure she could potentially reach the end-limit of her active trunk flexion (Figure 2). The resulting forward flexion produced a high degree of flexion allowing fingertips to easily touch the floor, but not the palms of the hands. It was decided to modify this test and measure the distance (patient on the stool) from the distal crease of the wrist to floor.

The SLR measurements followed a standard protocol described previously (Figure 3) (Moseley, 2004; Moseley, Hodges, and Nicholas, 2004; Zimney, Louw, and Puenteuda, 2014) as well as the PPT measurements (Fernandez-de-las-Penas et al, 2009, 2010; Mendez-Sanchez et al, 2011). The SLR was repeated twice on the involved (left) and uninvolved (right) leg and average scores were determined. Although not formally measured for ROM, the patient reported anterior pelvic tilt as her most provocative movement in the interview and was performed by the patient during the physical examination to determine its ability to provide a pain-provoking movement needed for the fMRI measurement during a painful task. Data from the physical tests can be found in Table 1.

![Figure 1. T2-weighted magnetic resonance images (MRI) of the lumbar spine demonstrating L5/S1 herniated disc.](image)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low back pain rating (VAS)</td>
<td>4/10</td>
</tr>
<tr>
<td>Left leg pain rating (VAS)</td>
<td>0/10</td>
</tr>
<tr>
<td>Disability (ODI)</td>
<td>26%</td>
</tr>
<tr>
<td>Fear of work (FABQ work sub-scale)</td>
<td>19/24</td>
</tr>
<tr>
<td>Fear of physical activity (FABQ physical activity sub-scale)</td>
<td>22/42</td>
</tr>
<tr>
<td>Neurophysiology pain knowledge</td>
<td>10/19</td>
</tr>
<tr>
<td>Pain catastrophization (PCS)</td>
<td>23/52</td>
</tr>
<tr>
<td>I feel prepared and ready for surgery (strongly agree [0] – strongly disagree [10])</td>
<td>7</td>
</tr>
<tr>
<td>I am afraid of the upcoming surgery (strongly agree [0] – strongly disagree [10])</td>
<td>5</td>
</tr>
<tr>
<td>I know what to expect after back surgery (strongly agree [0] – strongly disagree [10])</td>
<td>1</td>
</tr>
<tr>
<td>Back pain after surgery is to be expected (strongly agree [0] – strongly disagree [10])</td>
<td>8</td>
</tr>
<tr>
<td>Leg pain after surgery is to be expected (strongly agree [0] – strongly disagree [10])</td>
<td>10</td>
</tr>
<tr>
<td>I can control the amount of post-op pain (strongly agree [0] – strongly disagree [10])</td>
<td>5</td>
</tr>
<tr>
<td>Back surgery will fix my pain (strongly agree [0] – strongly disagree [10])</td>
<td>0</td>
</tr>
<tr>
<td>Lumbar flexion (distance from distal crease of wrist to floor)</td>
<td>10 cm</td>
</tr>
<tr>
<td>SLR (left leg)</td>
<td>148°</td>
</tr>
<tr>
<td>Pressure pain thresholds (average of 3 measurements)</td>
<td>23.23 kg/cm²</td>
</tr>
</tbody>
</table>

VAS, Visual Analog Scale; ODI, Oswestry Disability Index; FABQ, Fear Avoidance Beliefs Questionnaire; PCS, Pain Catastrophizing Scale; SLR, Straight Leg Raise.
The patient's surgery date was not finalized but per attending neurosurgeon indicated it would be in the next 2 weeks. The patient, apart from psychometric measures, verbalized a concern and general anxiety about undergoing lumbar surgery. The neurosurgeon indicated surgery was likely the preferred option due to the long history; persistent pain; high-level of performance of the patient; visibly worsening disk pathology on the latest MRI; and weakness in the right great toe extensors.

Clinical interpretation of the patient's case

The psychometric data, physical measurements and subjective examination portrayed a clinical picture of a high-level professional dancer presenting with an acute recurrent episode of LBP, intermittent left leg pain, worsening neurological deficit, with high levels of fear associated with her physical tasks and work requirements as a dancer. Furthermore, she held certain beliefs about surgery and recovery, and displayed a limited knowledge about pain. She presented with high levels of physical movement and high-pressure pain tolerance. Despite this, her scores indicated high levels of fear for both the impending surgery, as well as the uncertainty of the outcomes. Given her high level of dance performance and the fact that she, post-operatively, would need to physically and emotionally perform at a high level, it could be argued that her anxiety and fear was heightened, as she faced the possibility of not being able to return to her regular high-level activities (Hsu, 2010a, 2010b).

Functional magnetic resonance imaging (fMRI)

Four scans were acquired during the study. An imaging protocol used in a previous fMRI study examining brain activity before and after TNE was used for this case study (Moseley, 2005). A Philips Ingenia 3.0T fMRI scanner was used to acquire images, and the patient was placed supine with pillows under her knees and her head in a firm but comfortable restraint to ensure no movement of the head during the scan. An anatomical scan was acquired prior to the first session by having the patient relax and watch an animated movie (scan 1) (Figure 4).

After familiarizing the patients with the scanner, protocol and head position, a second resting scan was performed (scan 2). The brain activity during this anatomical scan phase (5 minutes) was considered the normal, resting brain activity during a pleasant, neutral experience such as watching an animated movie. The anatomical (resting level) scan would be used as a ‘‘canvas’’ to ‘‘paint’’ brain activity during the pain provoking task.

A block design was used such that the patient would rest for 30 seconds and then perform the pain provoking task for 30 seconds (indicated by ‘‘rest’’ and ‘‘contract’’ visual cues, respectively). This cycle was performed 5 times. In line with her subjective complaint of pain provocation and physical test, the pain provoking task was having the patient arch her lumbar spine (anterior pelvic tilt) and she reported that the pain remained constant until she released the anterior pelvic tilt and resumed a neutral position. Prior to image acquisition sequencing, we had the patient arch her lumbar spine and checked for any unwanted head motion. Visual observation of the patient during the anterior pelvic tilt task revealed 100% compliance with the task of the 5 × 30 second pain task of anterior pelvic tilt, both prior to and immediately after the education intervention. The fMRI thus yielded images of brain activation during a painful task for a patient scheduled for lumbar surgery for radiculopathy (scan 3) (Figure 5).

Statistical comparisons between the activity of the brain during the ‘‘contract’’ (painful task) condition and the ‘‘rest’’ (non-painful task) condition were made using statistical parametric software (Moseley, 2005).

The patient's surgery date was not finalized but per attending neurosurgeon indicated it would be in the next 2 weeks. The patient, apart from psychometric measures, verbalized a concern and general anxiety about undergoing lumbar surgery. The neurosurgeon indicated surgery was likely the preferred option due to the long history; persistent pain; high-level of performance of the patient; visibly worsening disk pathology on the latest MRI compared to previous MRI's; and weakness in the right great toe extensors.

Functional magnetic resonance imaging (fMRI)

Four scans were acquired during the study. An imaging protocol used in a previous fMRI study examining brain activity before and after TNE was used for this case study (Moseley, 2005). A Philips Ingenia 3.0T fMRI scanner was used to acquire images, and the patient was placed supine with pillows under her knees and her head in a firm but comfortable restraint to ensure no movement of the head during the scan. An anatomical scan was acquired prior to the first session by having the patient relax and watch an animated movie (scan 1) (Figure 4).

After familiarizing the patients with the scanner, protocol and head position, a second resting scan was performed (scan 2). The brain activity during this anatomical scan phase (5 minutes) was considered the normal, resting brain activity during a pleasant, neutral experience such as watching an animated movie. The anatomical (resting level) scan would be used as a ‘‘canvas’’ to ‘‘paint’’ brain activity during the pain provoking task.

A block design was used such that the patient would rest for 30 seconds and then perform the pain provoking task for 30 seconds (indicated by ‘‘rest’’ and ‘‘contract’’ visual cues, respectively). This cycle was performed 5 times. In line with her subjective complaint of pain provocation and physical test, the pain provoking task was having the patient arch her lumbar spine (anterior pelvic tilt) and she reported that the pain remained constant until she released the anterior pelvic tilt and resumed a neutral position. Prior to image acquisition sequencing, we had the patient arch her lumbar spine and checked for any unwanted head motion. Visual observation of the patient during the anterior pelvic tilt task revealed 100% compliance with the task of the 5 × 30 second pain task of anterior pelvic tilt, both prior to and immediately after the education intervention. The fMRI thus yielded images of brain activation during a painful task for a patient scheduled for lumbar surgery for radiculopathy (scan 3) (Figure 5).

Statistical comparisons between the activity of the brain during the ‘‘contract’’ (painful task) condition and the ‘‘rest’’ (non-painful task) condition were made using statistical parametric software (Moseley, 2005).
Lopes, 2007; Rosen, Svensson, and Nilsson, 2008; Salzwedel et al., 2008).

Considering this single-case fMRI study was based on a similar study by Moseley (2005) and the patient had several comparable signs and symptoms to his patient case study (i.e. years of LBP, leg pain, high fear, failed treatment, and pain medication), similar widespread brain activation was expected (Moseley, 2005). In the Moseley (2005) study, widespread brain activity occurred in areas known to be frequently activated in the pain neuromatrix (Butler and Moseley, 2003; Melzack, 2001). The fMRI scan in this case study indicated higher activity in 2 very specific brain regions which were deemed important to the interpretation of the scans: (1) significant activation in the cerebellum; and (2) activation of the periaqueductal gray (PAG) area. A third important observation revealed little to no activation of the motor cortex, which is expected with physical trunk movements (Tsao, Galea, and Hodges, 2008). In this case study the patient performed an active trunk movement (anterior pelvic tilt), which did not activate the motor cortex as expected (Flor, 2000, 2003; Tsao, Galea, and Hodges, 2008).

**Intervention**

**Preoperative neuroscience education**

The development of the PNET has been detailed elsewhere (Louw, Butler, Diener, and PuenteDura, 2013). The educational messages are designed to be delivered as one-on-one educational sessions to patients prior to lumbar surgery for radiculopathy along with the development of a patient booklet containing the same messages to provide patients with a written version of the content of the educational session. The main aim of the preoperative neuroscience educational program is to help patients reconceptualize their back, hip and leg pain as an increase in nerve sensitivity, up-regulation of the peripheral and central nervous system and defocus attention from nociceptive input via the tissues from the affected areas. The TNE message aims to reduce anxiety and uncertainty and thus promote positive expectations and beliefs. The structure of the developed TNE program consists of 6 sections (Table 2).

The PNET was designed to include: prepared pictures (Meeus et al., 2010; Moseley, 2004; Moseley, Hodges, and Nicholas, 2004; Ryan, Gray, Newton, and Granat, 2010; Van Oosterwijck et al., 2011); examples (Meeus et al., 2010; Moseley, Hodges, and Nicholas, 2004; Van Oosterwijck et al., 2011); and metaphors (Van Oosterwijck et al., 2011). The sensitivity of the nervous system, metaphorically described as an alarm system (Van Oosterwijck et al., 2011) accompanied with drawings of action potentials (Moseley, 2004; Van Oosterwijck et al., 2011) was used to describe peripheral sensitization (Moseley, 2004; Van Oosterwijck et al., 2011), central sensitization (Moseley, 2004; Moseley, Hodges, and Nicholas, 2004; Van Oosterwijck et al., 2011), and plasticity of the nervous system (Moseley, Hodges, and Nicholas, 2004; Van Oosterwijck et al., 2011) (Figure 6).

After completion of the two baseline fMRI’s and fMRI of the painful task, the patient was escorted to a private room to undergo a one-on-one verbal session of PNET with the primary researcher. The educational session lasted 30 minutes, and included questions and answers, open ended-questions for the patient to answer, drawings and descriptions of action potentials and nerve sensitivity. The patient was visibly intrigued by the program, alert and engaged.
Figure 5. Pre-neuroscience education fMRI scan of brain activation during the painful lumbar extension task (anterior pelvic tilt); (color images available online).
Outcomes

Psychometric measures and physical tests

After completion of the PNET, the patient was asked to complete the same intake forms she completed at the start of the session (Table 3). Additionally, the same physical measurements of forward flexion and SLR were repeated and recorded.

The most noticeable immediate positive changes in psychometric measures following the session included a 10% decrease in the ODI and a 10-point decrease in the PCS along with several positive changes in beliefs and attitudes regarding the impending lumbar surgery. Physically, the patient demonstrated increased SLR by 7 degrees on the left leg and forward flexion by 8 cm. Several measures showed little or no change, including: fear avoidance (total score, FABQ-W and FABQ PA); and pain knowledge (NPQ). In some categories, a negative effect occurred, including slight increased pain ratings and decreased PPT measurements.

fMRI post-education

The same fMRI protocol was repeated after the delivery of the PNET (scan 4). The patient once again completed 100% of her...
Table 3. Measurements pre- and post-TNE.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Pre-TNE</th>
<th>Post-TNE</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low back pain rating (VAS)</td>
<td>4</td>
<td>6</td>
<td>↑ 2</td>
</tr>
<tr>
<td>Left leg pain rating (VAS)</td>
<td>0</td>
<td>2</td>
<td>↑ 2</td>
</tr>
<tr>
<td>Disability (ODI)</td>
<td>26%</td>
<td>16%</td>
<td>↑ 10%</td>
</tr>
<tr>
<td>Fear of work (FABQ work sub-scale)</td>
<td>19</td>
<td>18</td>
<td>↓ 1</td>
</tr>
<tr>
<td>Fear of physical activity (FABQ physical activity sub-scale)</td>
<td>22</td>
<td>22</td>
<td>No change</td>
</tr>
<tr>
<td>Neurophysiology pain knowledge</td>
<td>10/19</td>
<td>12/19</td>
<td>↑ 2</td>
</tr>
<tr>
<td>Pain catastrophization (PCS)</td>
<td>23</td>
<td>13</td>
<td>↓ 10</td>
</tr>
<tr>
<td>I feel prepared and ready for surgery</td>
<td>7</td>
<td>5</td>
<td>↓ 2</td>
</tr>
<tr>
<td>I am afraid of the upcoming surgery</td>
<td>5</td>
<td>8</td>
<td>↑ 3</td>
</tr>
<tr>
<td>I know what to expect after back surgery</td>
<td>1</td>
<td>0</td>
<td>↓ 1</td>
</tr>
<tr>
<td>Back pain after surgery is to be expected</td>
<td>8</td>
<td>4</td>
<td>↓ 4</td>
</tr>
<tr>
<td>Leg pain after surgery is to be expected</td>
<td>10</td>
<td>9</td>
<td>↓ 1</td>
</tr>
<tr>
<td>I can control the amount of post-op pain</td>
<td>5</td>
<td>5</td>
<td>No change</td>
</tr>
<tr>
<td>Back surgery will fix my pain</td>
<td>0</td>
<td>1</td>
<td>↑ 1</td>
</tr>
<tr>
<td>Lumbar flexion*</td>
<td>10 cm</td>
<td>2 cm</td>
<td>↓ 8 cm</td>
</tr>
<tr>
<td>SLR (left leg)</td>
<td>148</td>
<td>155</td>
<td>↑ 7 degrees</td>
</tr>
<tr>
<td>Pressure pain thresholds</td>
<td>23.23</td>
<td>16.17</td>
<td>↓ 7.06</td>
</tr>
</tbody>
</table>

VAS, visual analog scale; ODI, Oswestry Disability Index; FABQ, Fear Avoidance Beliefs Questionnaire; PCS, Pain Catastrophizing Scale; SLR, Straight Leg Raise.

*pLumbar flexion was assessed with the patient standing on a 20 cm stool.

Discussion

To our knowledge, this is the first study where the effect of TNE on brain activation during a painful task is demonstrated on a patient scheduled for lumbar surgery for radiculopathy. The preoperative neuroscience education program resulted in positive changes in several psychometric measurements, the patient’s beliefs and attitudes regarding the impending lumbar surgery, physical movements and changes in brain activity.

The results from this single case study concur with various studies utilizing TNE (Louw, Diener, Butler, and Puenteleda, 2011; Moseley, 2002; Moseley, 2003a; Moseley, 2004; Moseley, Hodges, and Nicholas, 2004). Although the patient reported slightly higher pain levels following the education session (increase by 2 points for both low back and leg pain scores), TNE often produces no significant immediate changes in pain perception (Louw, Diener, Butler, and Puenteleda, 2011; Louw, Puenteleda, and Mintken, 2012; Moseley, Hodges, and Nicholas, 2004). Clinically, and a recent TNE study (Louw et al, submitted for publication), a slight increase in pain after a neuroscience educational program is quite common. This slight, immediate increase in pain (often referred to as ‘‘explain pain pain’’) is thought to due to an increased awareness and discussion of pain, pain issues and the word ‘‘pain,’’ which not only increases pain ratings (Wilson, Williams, and Butler, 2009), but may activate the pain neuromatrix via neighboring influences of neuronal maps (Puenteleda and Louw, 2012). Furthermore, it could be argued for patients seeking a true cognitive change, a deep learning process needs to occur (Crabtree, Royeen, and Mu, 2001; Sandberg and Barnard, 1997; Wittmann-Price and Godshall, 2009). Deep learning implies the reception of the information, processing of the information and applying the information to their specific condition (i.e. facing spinal surgery) (Wilson, Williams, and Butler, 2009). Deep learning is an emotional process addressing beliefs, fears, hopes and goals, which may in fact produce a greater awareness of the pain experience, which may manifest by a slight increase pain perception, before the perceived pain decreases, as is evident in this case study (Crabtree, Royeen, and Mu, 2001; Sandberg and Barnard, 1997; Wittmann-Price and Godshall, 2009). If pain, according to the modern definitions of pain, is an output as a defender of perceived threat, it may underscore the notion of a defense mechanism, in place for 4 years in this patient, not readily shutting off all pain (Butler and Moseley, 2003; Melzack, 2001; Moseley, 2007).

In contrast to perceived pain, the patient had improved movement, comparable to several other studies examining the immediate effect of TNE on physical tasks (Louw, Diener, Butler, and Puenteleda, 2011; Louw, Puenteleda, and Mintken, 2012; Moseley, 2004; Moseley, Hodges, and Nicholas, 2004). Even though the patient did not participate in functional tasks prior to re-measuring her disability, her perceived disability was lower on the ODI, comparable to other TNE studies (Louw, Diener, Butler, and Puenteleda, 2011; Moseley, Hodges, and Nicholas, 2004; Ryan, Gray, Newton, and Granat, 2010). We consider this the essence of TNE; the ability to function and move better despite pain. Pain is essentially ‘‘reconceptualized’’ (Moseley, 2007; Moseley, Hodges, and Nicholas, 2004). Pain is often seen as an indication of injury or disease (Sloan, Gupta, Zhang, and Walsh, 2008; Sloan and Walsh, 2010). TNE provides the patient another paradigm to explain their pain (i.e. nervous system sensitivity and the nervous system’s processing of nociceptive input) (Louw, Diener, Butler, and Puenteleda, 2011) and this allows for a reappraisal of threat. In lieu of the decreased threat, movements increase, function improves and various psychological perspectives change.

Even though our patient had several positive changes, expressed fear was not changed. Several TNE studies have clearly shown that scores in psychometric tests aimed at evaluating fear and fear-related measures, were reduced after TNE, but not in this case (Louw, Diener, Butler, and Puenteleda, 2011). Catastrophization though was markedly changed in this patient, similar to the study by Moseley, Hodges, and Nicholas (2004). Catastrophization is the process whereby a patient has irrational...
Figure 7. Post-neuroscience education fMRI scan of brain activation during the painful lumbar extension task (anterior pelvic tilt); (color images available online).
thoughts, believing a situation is far worse than it actually is. It is postulated that given the high demands of such a professional dancer, fear may have remained high, since the patient had little margin for error (Hsu, 2010a, 2010b, 2011). Lumbar surgery for radiculopathy is typically performed on middle-aged patients, of which few likely have such demanding physical tasks where a recovery of less than 100% may be disastrous (Dolan, Greenfield, Nelson, and Nelson, 2000; Ostelo et al, 2003). This interpretation is further enhanced by the fact that the patient reported less fear of the surgery after the educational session, which may indeed indicate greater fear associated with recovery (Hsu, 2010a, 2010b, 2011).

The patient demonstrated a marked shift in beliefs and expectations regarding lumbar surgery with an average of almost 3 points on a 10-point Likert scale. From unsure/ambivalent thoughts regarding being prepared for lumbar surgery, the patient reported feeling more prepared and a decreased self-reported fear of back surgery. The biggest change regarding surgery occurred in relation to her expectations of the outcomes. Prior to the educational session, the patient demonstrated a high degree of expecting pain to be abolished (back and leg) immediately after surgery. The patients’ starting score (untrained) in neurophysiology pain knowledge (Moseley, 2003b) (52%) was high in comparison to the study by Moseley (29%), and improved

<table>
<thead>
<tr>
<th>Description</th>
<th>Pre-education scan</th>
<th>Post-education scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Decreased activation of the PAG</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>2. Decreased activation of the cerebellum</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>3. Increased activation of the motor cortex</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
</tbody>
</table>

PAG, periaqueductal gray matter. Black circles and blocks indicate areas described in column 1 and main area of activation; (color images available online).
after the PNET to 63%, comparable to the Moseley study (61%) (Moseley, 2003b). The increased knowledge of the neurophysiology of pain may have likely provided the patient with a greater understanding that pain after surgery is expected. This is important, as several studies have correlated unrealistic expectations with poor lumbar surgery outcomes (Davidson et al, 2010; Toyone et al, 2005; Yee et al, 2008).

The fMRI results need to be carefully analyzed. fMRI, although increasingly utilized in pain studies, still have many unanswered questions (Moseley, 2008). Even if we consider all the potential pitfalls in our understanding of fMRI, this case study revealed notably different brain activations during a painful task in the same patient, before and after a preoperative neuroscience education program. Although the fMRI study by Moseley did not include performance of a painful task, it was decided to have the patient perform a painful task (anterior pelvic tilt) as a means to activate the pain neuromatrix. It was deemed acceptable to include a painful task in the study, given the patient’s long history of regularly performing while in pain, and her willingness to perform the painful task for the study. Furthermore, her subjective interview revealed anterior pelvic tilt as the most painful movement she endures while performing, rendering the anterior tilt as a fair measure of a personal (self-reported) painful task associated with her dancing career.

The three main brain area changes in the scans are intriguing. The PAG is the gray matter located around the cerebral aqueduct within the tegmentum of the midbrain (Burt, 1993). It plays a role in the descending modulation of pain and in defensive behavior (Fabian et al, 2009; Fernandez-de-las-Penas, Perez-de-Heredia, Brea-Rivero, and Miangolarra-Page, 2007). The ascending nociceptive fibers from the injured spinal level (L5/S1) send information to the PAG via the spinomesencephalic tract. Stimulation of the PAG activates enkephalins, serotonin and neurotransmitters aimed at modulating the incoming nociception (Villaneuva and Fields, 2004). With the high activation of the PAG initially (pre-education scan), it could be argued that the painful task of lumbar extension provided a nociceptive (A-d and C-fiber) barrage to the brain. This may have been further enhanced by the patient’s high levels of fear. In the post-education scan, the patient was provided with a different paradigm for her pain, de-emphasizing tissues as the “source of pain”, which may have deactivated the PAG’s immediate protective function.

The fact that the patient performed a physical task would imply the activation of the motor cortex of the brain (Tsao and Hodges, 2007). In the pre-education scan, no cortical activation is observed, but rather a significant activation of the cerebellum, more specifically the vermis and lateral lobes of the cerebellum. This activation is consistent with coordinated trunk activity. The vermis plays a significant role in various aspects related to movement potentially important to our high-level dancer including locomotion, coordination, strength, limb movements, planning and initiation and time of movements (Burt, 1993). Given the fact that our patient was supine (no locomotion) and a high level dancer, it could be postulated that the vermis activation may be related to the position she assumed (spinal extension), possibly even due to the fact she experienced pain in that posture. It is also important to realize that during a pain experience, such as this, the lower centers of the brain, including cerebellum activate prior to cortical activation, thus allowing lower centers of the brain to deal with immediate danger including basic protection, motor and autonomic dysfunction. The higher cortical areas, including motor cortex, deal more with motor planning, feelings and thoughts (Butler and Moseley, 2003; Tsao and Hodges, 2007). This lower-level activation could thus be interpreted as an immediate defense from the nociceptive input. After the neuroscience education the threat was changed, thus disengaging lower-level protection including the PAG and cerebellum, allowing higher cortical activation in the motor cortex, which may be associated with a restored, normal expected motor activation (Butler and Moseley, 2003; Tsao and Hodges, 2007). This possible change in cortical activation during the painful task could thus be correlated with the improved physical tasks of forward flexion and SLR in the absence of physical treatment.

Limitations

Several limitations apply to this case study. The results from any single case study have limitations to its application to a broader, general population. The fact that the patient was a high-level dancer further complicates the application to other patient populations. The PNET was designed specifically for decompressive lumbar surgery, and thus its effect for other types of spinal surgery such as fusion or disk replacement is unknown. The results from the fMRI are clouded in various discussions about the exact meanings of fMRI, and is based on the current knowledge and understanding of the interpretation of such imaging tests at this time.

Conclusion

This case is of interest because it describes the first-ever use of an fMRI evaluation of a neuroscience educational program specifically for lumbar surgery. Additionally, this program is the first of its kind as a pre-emptive program aiming to decrease potential pain and disability after surgery. The message of this case study is powerful for the physical therapist treating spinal pain patients, by underscoring the importance of education in leading to immediate changes in cognitions, ROM and beliefs regarding a patient’s perception of injury, treatment and potential recovery.

Declaration of interest

Primary author (AL) is the author of the booklet used in this fMRI study.

References

Fernandez-de-las-Penas C, de la Llave-Rincon AI, Fernandez-Carnero J, Cuadrado ML, Arendt-Nielsen L, Pareja JA 2009 Bilateral widespread


Flor H 2003 The image of pain. Paper presented at the Annual Scientific Meeting of The Pain Society (Britain), Glasgow, Scotland.


Moseley GL 2003b Unravelling the barriers to conceptualisation of the problem in chronic pain: The actual and perceived ability of patients and health professionals to understand the neurophysiology. Journal of Pain 4: 184–189.


