Qualitative modeling of pressure vs. pain relations in women suffering from dyspareunia

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Abstract: Genital pain / penetration disorders affect a significant portion of the female population and diminish significantly the quality of life of the subjects. Treatments, that often consist in stretching opportunely the vaginal duct by means of opportune vaginal dilators, are known to be invasive, lengthy and uncomfortable. Designing better treatments (e.g., more efficient locations and levels of pressures) nonetheless requires understanding better how the pressure developed in the vaginal channel affects the patient and leads to subjective pain. Here we take a control-oriented approach to the problem, and aim at describing the dynamics of the pressure vs. pain mechanisms by means of opportune state space representations. In particular, we first collect and discuss the medical literature, that describes how the variables that are involved in the treatment of genital pain / penetration disorders with vaginal dilators, are logically related. After this we translate (and complete) this set of logical relations into a qualitative model that allows control oriented analyses of the dynamics. The obtained state space model is then proved to both mimic correctly what is expected from logical perspectives and reproduce behaviors measured in clinical settings.

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1. INTRODUCTION

Female genital pain / penetration disorders affect a great number of persons (being estimated that 30-40% of women suffer from painful experiences during sexual intercourses (Goldstein et al., 2009, Chap. 2)), and arise from a great variety of causes (biological, psychological, social reasons, and the union of these (Goldstein et al., 2009, Chap. 3), with interpersonal and relational factors such as hostile partner responses and other psychosocial factors contributing to maintenance, exacerbation and chronicization of genital pain). Affected persons are known to be likely to develop comorbid sexual difficulties, negative affect, and relationship concerns (Goldstein et al., 2009, Chap. 3), all factors that diminish significantly the quality of life.

Treatments of genital pain / penetration disorders follow combinations of psychological perspectives (e.g., Cognitive Behavioral Therapies (CBTs) such as exposure, modifying, hypervigilance and catastrophizing strategies) and physiological perspectives (such as stretching the vaginal duct, desensitizing the vestibulum, and relaxing the pelvic floor) (Binik et al., 2006; Bergeron et al., 2008; Goldstein et al., 2011). These therapies are nonetheless known to be invasive, lengthy, intimate and scarce at the point that several patients rather prefer to go untreated and live with these debilitating disorders. The societal need is thus to adapt the treatments in order to increase their appealingsness.

Towards this goal, here we focus on the specific and common physiological treatment of stretching the vaginal duct by applying a certain pressure by means of opportune vaginal dilators. This strategy is indeed commonly used for treating disorders with components that are both psychosomatic (e.g., vaginismus) and physiological (e.g., complications after cervix cancer surgeries, vaginal radiotherapies, Mayer-Rokitansky-Küster-Hauser syndromes, or male-to-female gender reassignment surgeries).

We thus develop qualitative and quantitative models of the dynamics of the quantities involved in the treatment, i.e., how the pressure developed in the vaginal channel (plus some ancillary variables) transform into subjective pain. Our aim is thus to provide a mathematical tool that can be used to design novel vaginal pressure patterns (location, level of pressure, way of building up the pressure) with higher effectiveness than the current practice.
Delaying the discussion on the relevant literature to Section 3, our contributions consist in collecting the existing medical literature on the subject, translating and completing it into a state-space description of the dynamics of the relevant variables, and eventually analyzing the dynamics from mathematical perspectives (e.g., the positivity of the system, its equilibria and their stability properties).

The paper is structured as follows: Section 2 lists and discusses the variables involved in the treatment of genital pain / penetration disorders. Section 3 reviews the medical literature that describes qualitative relations among the variables listed in Section 2. Section 4 defines which variables above should be included and which ones should be excluded in a state-space representation of the system under investigation. Section 5 drafts the co-implications among the variables in our state-space representations, and Section 6 completes our translation efforts by presenting our final state-space model plus a mathematical analysis of it in Section 7. Section 8 concludes the paper with some remarks and indications for future research directions.

2. INVOLVED QUANTITIES

The following list contains the variables that are usually involved in the treatment of genital pain / penetration disorders by means of vaginal dilators. Note that this paper focusses on a qualitative model without considering exact mathematical values. Hence, the typical order of magnitude or dimension of the variables are not of interest.

- $u_{\text{pressure}} := \text{intravaginal pressure}$, physically corresponding to an actuation pressure signal. It can be measured numerically by means of opportune pressure sensors, but it is still unknown how a measured vaginal pressure relates to the muscular tension in the pelvic floor;
- $u_{\text{vibration}} := \text{vibration levels}$ of the vaginal dilator, physically corresponding to an actuation signal. As for $u_{\text{pressure}}$, it is numerically known but it is still unknown how it relates to the muscular tension in the pelvic floor;
- $u_{\text{stimulus}} := \text{visual sexual stimuli}$, physically corresponding to erotic movies with different arousal-level contents, and corresponding to an actuation signal measured subjectively through questionnaires;
- $x_{\text{pain}} := \text{affective-motivational dimension of the perceived level of pain}$, a subjective state that is measured subjectively\(^{1}\);

\(^{1}\) Importantly, pain is not a mono-dimensional feeling; one may indeed distinguish the following two dimensions:

- sensory-discriminative dimension of pain: dimension of pain relative to the sense of the intensity, location, quality and duration of the pain;
- affective-motivational dimension of pain: dimension of pain relative to the unpleasantness and urge to escape the unpleasantness.

For example, placebos may modulate the affective-motivational dimension while leaving the sensory-discriminative one unchanged (Melzack and Casey, 1968). Intensity and unpleasantness of a painful stimulus should thus be measured and treated independently; in this paper nonetheless we consider only the affective-motivational dimension since it is the unique one dimension usually measured in tests through dedicated devices called algometers.

$x_{\text{pleasure}} := \text{perceived and subjective level of pleasure}$, that for convenience is measured with the same measurement units with which $x_{\text{pain}}$ is measures;

$x_{\text{subj.arousal}} := \text{subjectively perceived sexual arousal levels}$, corresponding to the perceived current interest in sexual activity, and measured through opportune questionnaires (notice that in our settings we ignore the type of sexual activity the subject is interested into) or by means of opportune Visual Analogue Scale (VAS). Notice that $x_{\text{subj.arousal}}$ is different from the physiological arousal level $x_{\text{phys.arousal}}$ defined below, that instead corresponds to the physiological genital arousal (that translates into lubrication levels, blood congestion levels, etc.). Importantly, women may be physiologically aroused but not subjectively aroused; this implies that there may be low concordance between the two signals $x_{\text{subj.arousal}}$ and $x_{\text{phys.arousal}}$;

$x_{\text{phys.arousal}} := \text{physiological genital arousal level}$, a quantity that merges different and distinct physiological signals such as $x_{\text{lubrication}}$ (the vaginal lubrication levels) and $x_{\text{vasocongestion}}$ (the vaginal vasocongestion levels, that can be measured through thermography, by Doppler considerations on ultrasounds, or using Magnetic Resonance Imagings (MRIs) techniques). In this manuscript we lump the various signals together for simplicity, assuming implicitly that they have large concordance;

$x_{\text{muscles}} := \text{pelvic muscles tension / activity}$, known to be influenced by the intravaginal pressure $u_{\text{pressure}}$ but currently still not understood how;

$x_{\text{fear}} := \text{subjective fear level status}$, a situation-related quantity that is in principle measurable through opportune questionnaires or a VAS;

$x_{\text{touch}} := \text{perceived and subjective touch intensity}$, assuming that the intensity of the stimulus is beyond the threshold for which the stimulus is perceived, and also that the stimulus is neither associated to pain nor pleasure.

The following list instead contains some other ancillary mathematical quantities that are useful to define the logical relations among the variables listed above.

$T_{\text{touch}} := \text{touch perception threshold}$, which measurement unit depends on the type of stimulus applied to the patient (e.g., Pascal or mmHg if it is a pressure);

$T_{\text{pain}} := \text{pain perception threshold}$, which measurement unit depends on the type of stimulus applied to the patient (e.g., Pascal or mmHg if it is a pressure);

$S_{\text{pain}} := \text{pain sensitivity}$, i.e., the function that maps a certain stimulus (considered as a time-dependent signal) into a subjective pain level (considered again as a time-dependent signal);

$S_{\text{touch}} := \text{touch sensitivity}$, for which the same considerations for the pain sensitivity $S_{\text{pain}}$ also apply.

3. LITERATURE REVIEW

We now describe the known qualitative relationships among the variables introduced in Section 2.
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