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From finger friction and induced vibrations to brain activation: Tactile comparison between real and virtual textile fabrics

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ABSTRACT

The objective is to compare the tactile rendering of real and virtual textile surfaces. A grooved woven (twill) and a hairy fabric (velvet) were studied. The virtual fabrics were simulated with a tactile device. The comparison was done by measuring the finger interaction in terms of coefficient of friction (COF) and induced vibrations, and brain activation by electroencephalography (EEG). EEG showed that the real and virtual twill fabrics are close, contrary to real and virtual velvets. The finger friction showed that for both fabrics the rendering of virtual compared to real fabrics is very good in terms of COF, low in terms of finger induced vibrations in high frequencies, but differs for the velvet texture for low frequencies.

1. Introduction

The possibility to simulate the touch feeling of surfaces is of high importance for many applications: e-commerce for products in direct interaction with humans (garments, car upholstery and dashboard, furniture …) [1], virtual prototyping as design assistance [2], and also tactile deficiency detection and patient rehabilitation.

In the textile field, tactile simulation could be used by the final consumer to choose a textile material sold through the internet [1,3–5]. In the near future, it might be common to have one's own 3D body shape [6], to choose a fabric in terms of colour, texture and drape, to choose a garment shape and to simulate individual avatars wearing virtual garments [2,7]. In pursuing these goals it is therefore essential to improve the touch rendering of the virtual fabrics [8]. In this field, few papers report simulation of textile fabrics with a tactile device. The tactile device used can be a friction modulation device based on ultrasonic vibration [9] or an array of 256 pin-electrodes allowing lateral finger movement [10]. In both cases, the control signal is generated from the surface textile modelled by its surface microgeometry. Therefore, the adhesion or deformation of the surface, i.e. the friction behaviour, is not taken into account.

One's ability to perceive different fabrics involves both cortical and peripheral mechanisms. The tactile afferents from the finger signal the transformation of soft tissues that occurs when the fingers interact with objects and thus provide information about the physical properties of the fabrics and the contact between the fabric and the finger. The brain uses the tactile afferent information related for example to the friction between contacted fabrics and the digits to categorise the fabric. Categorisation is the process by which sensory stimuli are recognised, differentiated, and placed into groups. Through this cognitive process the physical properties of the stimuli are transformed into knowledge of the fabric under the digits. But it is not known how, or even whether, the perception of virtual stimuli is modified during movement exploration.

The literature reported results about friction between human finger or skin and textile fabrics [11–15]. Most of them used the coefficient of friction (COF). Nevertheless it is known since more than an half century that the COF is necessary but not sufficient to characterise fabric touch [16–18], therefore it can be supposed it is not sufficient for simulating fabric touch. More recently, from the consideration of the duplex tactile theory of tactile texture perception, some studies consider finger induced vibrations from tactile surfaces [19–21]. For a given fabric a specific spectrum can be obtained [19,20].

Few papers reported studies of fabric touch with electroencephalography (EEG) and none on virtual textures. The tactile comfort during clothing wear has been evaluated with EEG, and it was observed the higher the shirt mass density, the higher the energy percentages at both the left and right occipitalia [22]. Recently, the COF between human fingers and textile fabrics, induced vibrations from an artificial finger and perception in terms of different descriptors (rough-

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smooth, coarse-fine, complex-uniform and surface comfort), have been correlated with EEG results [23]. It is quite difficult to extract results in a textile material point of view because the textile surfaces used are not precisely described. Specifically the weave pattern is not indicated. Nevertheless, the descriptors used are linearly correlated with the COF which is probably due to the choice of the fabrics investigated. In fact, the most influential parameter is the size of the elementary mesh linked to the number of warp and weft yarns per centimetre and the yarn count. The silk fabric is probably the smoothest, and it reveals a higher real contact area. Moreover, the direction of movement, i.e. in the warp or weft direction, is not indicated. It seems the movement is anteroposterior.

In a previous study [24,25], three very different fabrics have been simulated from a tactile stimulator named STIMTAC. The objective was to show if the human participants were able to associate the virtual fabric to the corresponding real fabric. The results obtained showed in 80% of cases a virtual fabric has been associated to the correct real fabric [24]. Nevertheless, the distance between the real and the virtual fabrics has not been evaluated. The goal of this paper is to compare finger behaviour and cortical responses during a tactile task in a lateral finger movement for real or virtual fabrics, in terms of finger friction, induced vibrations and brain activation measured with EEG. The idea is to use further the analysis of the differences between virtual and real surfaces to improve the design and control of the tactile simulators.

The paper is organised as following: first, the experimental apparatus and methods both for tribological and EEG measurements are described; then the results are shown, highlighting the differences between virtual and real surfaces for two kinds of fabrics. Last, the discussion gives a first analysis and explanation of these differences.

2. Materials and methods

2.1. Real and virtual textile fabrics

Two fabrics have been investigated: a twill woven fabric and a velvet knitted fabric. The twill fabric is obtained by interlacing two yarns in the plane of the fabric in two orthogonal directions. This fabric is rather compact with 44 warp and 37 weft threads per centimetre. The yarns consist of filaments (97% polyethylene terephthalate, i.e. PET, and 3% elastane), therefore the surface hairiness is very weak. The yarn fineness is 26 tex (1 tex = 1 g/km). The intercrossing of the yarns generates a fabric with relief in the form of inclined ribs (19.5 ribs or grooves/cm) (Fig. 1a–b).

The second fabric is very hairy and is obtained by knitting a ground yarn (in PET) forming the knitted structure, with some acrylic fibres introduced in the ground structure during the loop formation in order to form bristles/plush yarns (Fig. 1c). The acrylic fibres are shaved at a fixed length when they are caught in the knitted structure. The released bristles make up the pile and are in the form of fibre bundles held on one side of the structure. The bristles obtained are parallel and of equal length (about 2 mm). For this fabric which will be named velvet afterwards, the pile has a preferred direction in which it lies down, as with the fur of an animal. This preferred direction is called the "along pile" direction while the opposite direction is the "against pile" direction.

The virtual textile fabrics are simulated from the tactile device STIMTAC from a method described elsewhere [24–26]. STIMTAC is a continuous tactile stimulator and looks like the touchpad of a laptop computer (Fig. 2). STIMTAC provides a constant stimulation all over the touched surface at a given time. It is based on the reduction of the COF which is obtained with ultrasonic vibrations (30–40 kHz) of the touched plate forming an air gap acting like a lubricant. The frequency of vibration of the plate is too high to be perceptible by the human hand which cannot perceive vibrations higher than 1 kHz [27,28]. The measurement of the finger position allows to change the plate vibration amplitude, i.e. the COF, every 0.1s (100 Hz). The simulation protocol of the investigated fabrics, i.e. the twill and the velvet fabrics, has been described elsewhere [24,25]. The friction signal obtained from the considered fabrics and specific sliders has been recorded. The instantaneous COF is obtained for each surface and used for the command signal of STIMTAC for a given virtual fabric [29,30]. The surface of the samples (real as virtual) was 80 × 50 mm^2.

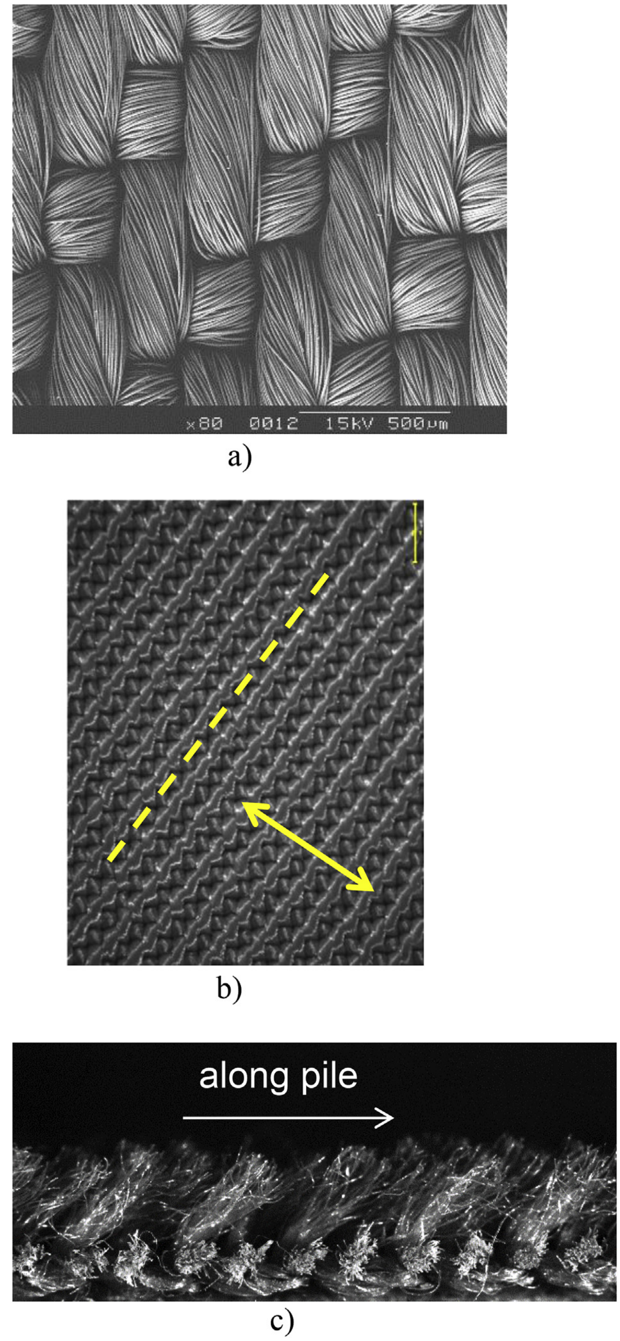

Fig. 1. Investigated surfaces a) 2/1 twill, b) twill with a dashed line on one rib (the arrow materialising the direction of friction) and c) velvet fabric.

2.2. Participants and tasks

Nine right-handed participants without any known neurological, physiological, cognitive and motor disorders (4 women and 5 men) participated in the experiment (28–57 years with an average of 44). All procedures performed were in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.