THE EVALUATION OF THE FRICTION CHARACTERISTICS OF DIFFERENT PIQUES USED FOR HANDLING PATIENTS

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ABSTRACT

The objective of this work was to examine the friction characteristics of the piqué used by nursing aides for handling patients. The piqué has been associated with a large number of injuries. Mechanical tests were administered to evaluate 3 different types of piqué, 2 conditions of wear and the interactions with different types of sliding surfaces (2 types of drawsheet) and weights (2 conditions). Both the static and dynamic friction coefficients were measured. Factorial analyses of variance showed that: (i) the performance of the piqué, preferred by nursing aides, was superior and (ii) the sliding conditions affected the friction characteristics. Several validity question are raised to show the risk of extrapolating results to practical situations.

RELEVANCE TO INDUSTRY

Sliding characteristics of the materials being handled during pushing/pulling tasks are important in explaining accidental falls. Container designs must seek a compromise between very slippery conditions, which increase the risks of falling, and conditions with minimum slippage, which increase stresses on the body joints.

KEYWORDS

Nursing aides, equipment, friction coefficients, sliding, handling tool, biomechanics.
INTRODUCTION

Nursing aides are particularly exposed to lower-back problems (Stubbs et al., 1983; Harber et al., 1985). Lortie (1987) conducted a study of accidents in a chronic care facility. She reported that patient handling was an important source of accidents; in fact, 47% of all accidents in female nursing aides could be related to "in-place" manoeuvres (as opposed to transfer manoeuvres). The action most frequently associated with accidents was pulling and/or turning patients across the width of the bed. This action was associated with about half of the accidents reported in the "in-place" category. In this manoeuvre, the piqué which is a waterproof padded sheet placed under the incontinent patient, is usually utilized as a handling tool.

This study revealed that injuries to upper limbs were also significant. More specifically, 42% of back injuries and 38% of upper limb injuries were attributed to pulling/turning actions.

From these results, it was decided to study, using biomechanical methods, the execution parameters of the pulling/turning task for the purpose of identifying a "best" mode of action (Gagnon et al., 1987a,b). The study was conducted using 15 female nursing aides. The results showed the difficulty in determining a "best technique" when using several evaluation criteria. However, a subsequent study (Gagnon et al., 1988b) showed that a breakdown of the task into several operations (pulling and turning separated by a pause) was indicated.

The second objective of our investigation was to examine the characteristics of the piqué such as the types of piqûes, the levels of wear, the drawsheets or surfaces onto which the piqué slides, and the weight in contact with the piqué.

The three different types of piqué chosen for the study were Courey, Med-I-Pant and Dagenais. The Courey piqué had two layers of cotton and was not waterproof, so its use was supplemented with a rubber sheet covered by a drawsheet. The other two types of piqué also include the rubber sheet. Their difference was in the type of layer in contact with the drawsheet over which the piqué slides when it is pulled. The Courey piqué had been replaced by the other two piqûes for economic reasons since they involved lower washing costs, but they had however generated complaints from nursing aides who judged them more difficult to use for handling. These facts justified the present study.

Another point of interest was the level of wear, which is associated mainly with the effects that washing and the use of cleansing products have on the performance of the piqûé. With this aspect, the examination was restricted to two conditions for only one type of piqué, the Dagenais; these conditions were the following: new versus 3 months of use, represented by about one washing a day.

When sliding, the qualities of static and dynamic friction are determined by the two contacting surfaces; in the present situation, the piqué slides over a drawsheet. Two types of drawsheets were examined; they were commercially-available types characterized by the relative amounts of polyester and cotton in their composition (soft fabric: 20%/80%, and regular: 50%/50%).

Finally, the relative weight in contact with a piqué may have an effect upon its sliding characteristics. Two types of weight were used to simulate that part of the patient's body weight in contact with the piqué.

Two experimental approaches can generally be adopted to evaluate equipment: a biomechanical approach which favours the testing of equipment with human subjects during the actual performance of the task, or a mechanical approach which favours the testing of equipment under strictly controlled laboratory conditions simulating real conditions. In a biomechanical evaluation, the validity conditions are optimized but the reproducibility conditions may be negatively affected by the generally large inter- and intra-subject variabilities associated with human performance; in a mechanical evaluation, the measurements are generally highly reproducible but the greatest challenge in this approach is to simulate real conditions in such a way that the results may be interpreted in relation to real life situations.

A biomechanical investigation was first conducted to evaluate the effects in relation to the conditions of the piqué during the actual performance of the pulling/turning task (Gagnon et al., 1988a). The results have shown that very few differences could be detected. It was therefore judged important to carry out other investigations...
and to examine the mechanical characteristics of the piqué under controlled laboratory conditions. The static and dynamic friction coefficients were evaluated for different types of piqué and conditions of utilization.

**METHODOLOGY**

**Methods**

Static and dynamic coefficients were measured using different experimental procedures. Sliding occurred on a rigid wood board which was covered by one of the two draw sheets (test condition); a metallic block was designed to hold different weights, distributed equally over the surface, and was covered on its lower surface by the piqué (pressure simulating real conditions). The set-up is presented in Fig. 1. Preconditioning was applied before each test by making the system slide for 5 consecutive trials.

For static tests, the board was inclined at an angle inferior to the one estimated critical for impending motion; the inclination was slowly increased in successive steps of $2^\circ$ until sliding occurred; thereafter, the inclination was decreased by successive $0.5^\circ$ intervals until it reached the static condition after a waiting period of at least 60 s.

For dynamic tests, the plane was fixed at $40^\circ$, an angle that more realistically reproduced the in vivo conditions of velocities associated with pulling/turning the patient (between 0.5 and 1.5 m/s).

A piezoelectric accelerometer was aligned on the block along an axis parallel to the inclined plane; the block was originally maintained at rest with an electromagnet. During sliding, the acceleration signals were recorded on a PDP11/23 mini-computer. The acceleration signals were validated by comparing the velocity data obtained from integration of the acceleration signals with the velocity data obtained by differentiating linear displacements of the system as measured with a potentiometer. The acceleration was nearly constant (except at the beginning of sliding) and the value of the dynamic coefficient was found to vary very little with velocity; therefore a regression line of order zero was determined to express this coefficient.

The values of the static coefficient ($\mu_s$) and the dynamic coefficients ($\mu_D$) were determined in the following manner:

$$\mu_s = \tan^{-1} \alpha_1$$

$$\mu_D = \tan^{-1} \alpha_2 - \left( \frac{a}{g \cos \alpha_2} \right)$$

where "$\alpha_1$" and "$\alpha_2$" are the plane angles under the static and dynamic conditions, "$a$" is the measured acceleration and "$g$" is the gravitational acceleration.

**Experimental treatments**

The experimental treatments referred to 3 types of piqué (Courcy, Med-I-Pant, Dagenais), 2 levels of wear (new and 3 months) and 2 types of drawsheet (soft fabric and regular). Furthermore, 2 types of weight were used (17 and 22 kg) which simulated percentages of different patients’ body weights in contact with the piqué (a light patient of 51 kg, and a heavier patient of 66 kg). About 1/3 of the weight was assumed to be in contact with the piqué. Five different samples were tested for each type of piqué and each level of wear; each sample was tested 10 times under each of the 2 weight conditions and the 2 drawsheet conditions.

**Statistical analyses**

Factorial analyses of variance were performed to investigate whether there were significant dif-
ferences for the main factors (piqués; wear; drawsheets; weights; repetitions) and their interactions. Two analyses were performed; in the first case, the total variation was divided into two sources, which included one factor called inter-subjects (this referred to the types of piqué) and three factors called intra-subject (drawsheets, weights, repetitions); the second case was similar, with the inter-subjects factor being the level of wear and the intra-subject factors being the drawsheets, weights and repetitions. The statistical analysis of such experiments is described in Winer (1971), and all computations were performed using the BMDP statistical software (Dixon, 1983).

Validation procedures

Some validation procedures were also applied to the same samples of piqués for which four repetitions were performed. In this particular case, sliding occurred on a deformable mattress (as used under real conditions) instead of a rigid board. This was done to verify whether the type of surface affected the direction of the results. For the experiment, the mattress was positioned on an inclined plane and similar procedures as for the rigid board were adopted.

RESULTS

The results showed that the different samples for each type of piqué were very homogeneous, with coefficients of variation varying between 1.2 and 3.1%; similarly, there was very little intra-sample (or repetition) variation, the largest coefficient of variation being 2.2%. These results were similar for the static and dynamic conditions.

The differences in the friction coefficients between the types of piqué, the levels of wear, the types of drawsheet and the weights are presented in Table 1; for significance the level was fixed at 0.05. The results show that the Courey piqué presents better sliding characteristics than both the Med-I-Pant and the Dagenais. This difference was more important under static conditions (13 and 21% relative to the Dagenais and the Med-I-Pant) than under the dynamic conditions (2 and 6%). There was a small but statistically significant effect attributed to the level of wear, which indicated that the cleansing products may have altered the properties of the fibers by reducing their sliding properties: these differences were 3% and 8% respectively for the static and dynamic conditions. The composition of the drawsheets also had a slight effect and the fabrics containing the highest percentage of cotton presented less resistance to sliding under static conditions (7%) as well as under dynamic conditions (1%); because of its higher cotton content, this fabric was also softer on the patient's skin. The results showed that the weight applied on the piqué may affect its sliding characteristics. Lower friction coefficients were found with the heavier weight (11% differences in the static condition and 8% in the dynamic condition). Finally, there was a slight repetition effect and the friction coefficients tended to decrease linearly with the repetitions (1.3% and 3.3% respectively for the dynamic and static conditions); these results suggest that the number of preconditioning trials may have been insufficient.

Some interactions were found between the piqués and the drawsheets (dynamic condition), between the piqués and the weights (static and dynamic conditions) and between the levels of wear and the weights (static and dynamic conditions).

Sliding performances of the piqués were affected differently by the sliding surfaces or the

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean values for the static (μ_s) and the dynamic (μ_D) friction coefficients for the types of piqué, the levels of wear, the drawsheets and the weights and the probability levels for the null hypothesis of the equality of means (sliding condition: rigid board)</td>
</tr>
<tr>
<td>Main factors</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Types</td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>Wear</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Draw-sheets</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Weights</td>
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<td></td>
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</tbody>
</table>
types of drawsheet used (Table 2). The results showed that, in the dynamic condition, the Dagenais slid better with a regular drawsheet than with a softer drawsheet (contrary to the results of the main effects in Table 1 where sliding was easier with the softer drawsheet); on the other hand, the Med-I-Pant followed the trends for the main effects and slid better with the softer drawsheet; finally, the Courey piqué was not affected by the type of drawsheet.

On the other hand, the interactions between the types of piqué and the weights in both the static and dynamic situations also presented some important effects but only in the order of magnitude of the changes in the friction coefficients (Table 3); the trends observed in the main effects remained the same.

Similarly, significant interactions were observed between the levels of wear and the weights in both the static and the dynamic situations (Table 4) only in the order of magnitude of the differences between the weights or between the levels of wear.

To summarize, there were some interactions between the main effects which mainly reflected differences in the order of magnitude of the results excepted between the piqués and the drawsheets.

The validation results obtained from sliding the system on the bed mattress positioned on an inclined plane were similar to those obtained with the rigid board surface. The coefficients of variation varied between 0.9 and 4.6%. Table 5 presents the friction coefficients and it can be observed that the direction of the results remains similar to the one observed under the rigid board sliding condition (except for an inversion between the Med-I-Pant and the Dagenais under dynamic conditions). However, the values of the coefficients were higher when the bed mattress was used in comparison to a rigid surface; this was due to the fact that the bed mattress was deformable.

The patterns representing $\mu_D$ as a function of velocity became linear at some point when reaching about 30–40% of the maximum velocity, under the conditions using the rigid board surface; however some fluctuations were continually present with the bed mattress. The higher fluctuations encountered with the bed mattress were attributed to the fact that the surface was deformable and

**TABLE 2**
Mean values of the dynamic ($\mu_D$) friction coefficients for the significant interaction $^a$ between the types of piqué and the drawsheets (sliding condition: rigid board)

<table>
<thead>
<tr>
<th>Types of piqué</th>
<th>Drawsheets</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regular</td>
<td>Softer</td>
<td></td>
</tr>
<tr>
<td>Courey</td>
<td>0.636</td>
<td>0.630</td>
<td></td>
</tr>
<tr>
<td>Med-I-Pant</td>
<td>0.678</td>
<td>0.659</td>
<td></td>
</tr>
<tr>
<td>Dagenais</td>
<td>0.642</td>
<td>0.652</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ The observed significance level = 0.001

**TABLE 3**
Mean values of the static ($\mu_S$) and dynamic ($\mu_D$) friction coefficients for the significant interactions $^a$ between the types of piqué and the weights (sliding condition: rigid board)

<table>
<thead>
<tr>
<th>Types of piqué</th>
<th>Weights</th>
<th>$\mu_S$</th>
<th>$\mu_D$</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17 kg</td>
<td>22 kg</td>
<td>17 kg</td>
<td>22 kg</td>
<td></td>
</tr>
<tr>
<td>Courey</td>
<td>0.513</td>
<td>0.446</td>
<td>0.660</td>
<td>0.606</td>
<td></td>
</tr>
<tr>
<td>Med-I-Pant</td>
<td>0.621</td>
<td>0.567</td>
<td>0.694</td>
<td>0.643</td>
<td></td>
</tr>
<tr>
<td>Dagenais</td>
<td>0.588</td>
<td>0.517</td>
<td>0.680</td>
<td>0.614</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ The observed significance levels are 0.006 for $\mu_S$ and 0.001 for $\mu_D$.

**TABLE 4**
Mean values of the static ($\mu_S$) and dynamic ($\mu_D$) friction coefficients for the significant interactions $^a$ between the levels of wear and the weights (sliding condition: rigid board)

<table>
<thead>
<tr>
<th>Levels of wear</th>
<th>Weights</th>
<th>$\mu_S$</th>
<th>$\mu_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>17 kg</td>
<td>0.561</td>
<td>1.007</td>
</tr>
<tr>
<td>3 months use</td>
<td>22 kg</td>
<td>0.505</td>
<td>1.013</td>
</tr>
</tbody>
</table>

$^a$ The observed significance levels are 0.002 for $\mu_S$ and 0.045 for $\mu_D$.

**TABLE 5**
Mean values for the static ($\mu_S$) and the dynamic ($\mu_D$) friction coefficients for the types of piqué and the levels of wear (sliding condition: bed mattress)

<table>
<thead>
<tr>
<th>Main factors</th>
<th>Levels of wear</th>
<th>$\mu_S$</th>
<th>$\mu_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types</td>
<td>Couray</td>
<td>0.582</td>
<td>1.007</td>
</tr>
<tr>
<td></td>
<td>Med-I-Pant</td>
<td>0.684</td>
<td>1.013</td>
</tr>
<tr>
<td></td>
<td>Dagenais</td>
<td>0.640</td>
<td>1.043</td>
</tr>
<tr>
<td>Wear</td>
<td>Dagenais (3 months)</td>
<td>0.640</td>
<td>1.043</td>
</tr>
<tr>
<td></td>
<td>Dagenais (new)</td>
<td>0.621</td>
<td>0.957</td>
</tr>
</tbody>
</table>
also that the accelerometer could not be kept properly aligned in parallel to the axis of the plane.

Finally, some observations can also be made with regard to the specificity of the $\mu_D$ curves as a function of velocity for the different types of piqué (Fig. 2). The period of time to reach the steady state was highly variable, with the Dagenais having the shorter time and the Courey the longest period. These differences may have reflected some different elastic properties of the fibers. Even if the piqué was strongly attached to the sliding block, relative motion could be present, partially due to the elasticity of the fibers. It was difficult to predict this behaviour a priori and it is possible that having restricted the evaluation to the steady state might have resulted in the omission of important factors.

**DISCUSSION**

It is not a new situation that a piece of equipment be used for different purposes than those for which it was designed. The results of the present study show the importance of paying attention to the equipment as it is actually used in the field. In this study, a piece of equipment which was apparently of little importance showed an important impact. The differences between the piqués were statistically significant; these differences were particularly important for the Courey piqué under static conditions: the static friction coefficients were 19% and 13% smaller than the ones observed for the Med-I-Pant and the Dagenais respectively. This strongly suggests that one should consider the friction characteristics in handling situations.

The subjective opinions of the nursing aides also suggested that the Courey piqué allowed the patient to be slid more easily. Therefore, it must be emphasized that workers' opinions should be given full consideration before modifying workplace design and implementing new equipment.

Specific design aspects are discussed: these are the sliding conditions represented by the level of wear and the type of drawsheet. The cleansing products seem to alter the properties of the fibers in a direction which makes sliding more difficult: it is more apparent under dynamic conditions. The effect of wear should then be considered in the design. The composition of the drawsheet has an effect on the sliding properties, especially under static conditions; apparently a higher cotton content makes sliding easier; since this is also softer for the patient's skin, it should be recommended.

In the future, the design of the piqué should take into consideration the sliding characteristics as well as resistance to tear; this approach has become imperative in maximizing safety factors since the piqué is used as a tool for handling patients in some hospitals.

The applied weight was another question of interest. The weight represented that part of the body in contact with the piqué. The results indicated that the weight supported by the piqué affects its sliding characteristics. An increase in weight was associated with a decrease in the friction coefficients. The experimental weights were chosen to explore the relative importance of this factor rather than to extrapolate the results to real patients. It is difficult to speculate about the true friction coefficients under conditions where patients are being pulled by nursing aides. It is probably in the mid-range between 0 and 1. The designer should attempt to reach a compromise between very slippery conditions which would require constant adjustments of the piqué in the bed, and the absence of slippery conditions where the piqué could hardly be used as a handling tool. One should note that the surface in contact with the bed (involved in sliding) is different from the surface in contact with the patient.

The study of interactions between the main factors has indicated the importance of consider-
ing the interface (both contacting surfaces, weight applied) when analyzing the sliding characteristics of materials. One should be careful when extrapolating the results. The results have shown that interactions were significant and were reflected mainly in the order of magnitude of the changes between the treatments; however, one case was observed where the trends of the main effects were reversed. This is a very complex question since the changes occur at the fiber level and the behaviour is hardly predictable.

The conditions used in this study were highly reproducible due to the fact that all factors could be rigorously controlled under laboratory conditions. The results pertaining to the low coefficients of variation between the samples and between the measurements reflected the homogeneity of the samples and the absence of contaminating noise in the data.

Several factors affect friction coefficients: humidity, temperature, pressure, area of contact, sliding velocity. They have been discussed by Rubinstein (1958/1959). Much care was taken during the tests to reproduce as exactly as possible the conditions encountered in real situations (weights applied and pressure exerted which simulate the patient; speeds of sliding, approximating those encountered when pulling the patient; sliding surfaces). However, a few validity questions could be raised from the results which reveal the risk of transposing results obtained from simulations to practical situations.

A first question involves the sliding surface adopted for testing: the rigid board surface was associated with highly reproducible results, whereas the bed mattress surface produced some noise in the results due to the fact that this surface was deformable. The results of $\mu_D$ greater than 1.0 also indicated that some jerking might have occurred when using the bed mattress. The results showed similar direction (excepted for one case) with both surfaces, but the magnitudes of the friction coefficients cannot be interpreted. The use of a mattress in the experimental design would better approximate reality but it would be more difficult to demonstrate the statistical trends.

Another question refers to the choice of velocity for the evaluation of dynamic friction coefficients. For the testing of yarns, the American Society for the Testing of Materials (ASTM) recommends that the relative velocity be maintained constant (Annual Book of ASTM Standards, 1986); however, the ASTM does not provide any experimental protocol for the dynamic testing of fabrics; we chose to test under conditions of variable velocity, reproducing the range of values encountered during real situations. These conditions were more realistic, but experimental values of $\mu_D$ larger than $\mu_S$ were thus produced, which reflects an atypical situation. If $\mu_D$ had been tested at the same plane angles as $\mu_S$, its values should have been smaller than for $\mu_S$ but sliding velocities would have been found smaller than those in real situations.

Finally, a third question concerns the specificity of the $\mu_D$ curves as a function of velocity for the different piqués: the time difference to reach the steady state might reflect different properties of elasticity of the various types of piqué. This factor could not be examined in the present study, and its possible importance could not be assessed.

These questions were raised to illustrate the challenge in simulating real performances and to suggest that it might be potentially hazardous to directly extrapolate laboratory results to real life situations. Even slight changes in the protocol may have important effects on the results. There is apparently a trade-off between validity and reliability.

**CONCLUSIONS AND RECOMMENDATIONS**

On the basis of these results, one may conclude that the sliding properties of the piqué are affected by its composition. The worker’s opinion should be given full consideration in designing and redesigning the workplace. Whenever possible, complementary biomechanical and mechanical evaluations of the equipment should be used. Piqué design should not only focus on the sliding properties but also on resistance to tear in order to reduce the risk factors associated with the use of the piqué as a handling tool.
ACKNOWLEDGEMENTS

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