Abdul-Bari, M. M., McQueen, R. H., Nguyen, H., Wismer, W. V., de la Mata, A. P., & Harynuk, J. J. (2018). Synthetic clothing and the problem with odor: Comparison of nylon and polyester fabrics. Clothing and Textiles Research Journal, Volume: 36, Issue: 4, pp. 251–266. Copyright © 2018 ITAA. DOI: doi.org/10.1177/0887302X18772099

Synthetic clothing and the problem with odor: Comparison of nylon and polyester fabrics

Acknowledgements
We wish to thank the participants who volunteered to take part in this study and Mari Bergen for help in preparing the manuscript.

Mohammed M Abdul-Bari, Graduate student
Address: Department of Human Ecology, University of Alberta, Edmonton, Alberta, T6G 2N1, Canada; Fax: 1 780 492 4821; Email: abdulbar@ualberta.ca

Rachel H McQueen, Associate Professor **(corresponding author)**
Address: Department of Human Ecology, University of Alberta, Edmonton, Alberta, T6G 2N1, Canada; Phone: 1 780 492 2045, Fax: 1 780 492 4821; Email: rachel.mcqueen@ualberta.ca

Ha Nguyen, Graduate student
Address: Department of Agricultural, Food and Nutritional Sciences, 4-10 Agriculture and Forestry Centre, University of Alberta, Edmonton, Alberta, T6G 2P5, Canada; Fax: 1 780 492 4615; Email: hn1@ualberta.ca

Wendy V Wismer, Associate Professor
Address: Department of Agricultural, Food and Nutritional Sciences, 4-10 Agriculture and Forestry Centre, University of Alberta, Edmonton, Alberta, T6G 2P5, Canada; Phone: 1 780 492 2923; Fax: 1 780 492 4615; Email: wwismer@ualberta.ca

A Paulina de la Mata, Research Associate
Address: Department of Chemistry, University of Alberta, Edmonton, Alberta, T6G 2G2, Canada; Fax: 1 780 492 8231; Email: delamata@ualberta.ca

James J Harynuk, Associate Professor
Department of Chemistry, W3-39B Chemistry Building, University of Alberta, Edmonton, Alberta, T6G 2G2, Canada; Phone: 1 780 492 8303; Fax: 1 780 492 8231; Email: james.harynuk@ualberta.ca

Corresponding author is Rachel H McQueen.

Funding
In the Department of Human Ecology, the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Faculty of Agricultural, Life and Environmental Sciences are acknowledged for financial support. In J.J. Harynuk's laboratory in the Department of Chemistry, Alberta Innovates Technology Futures, NSERC, Genome Canada, and Genome Alberta are acknowledged for financial support related to this study. Leco, The Canada Foundation for Innovation (CFI) and the Government of Alberta are acknowledged for their support in obtaining the GC×GC-TOFMS system.

Synthetic Clothing and the Problem with Odor: Comparison of Nylon and Polyester Fabrics

Odor arising from the axilla (underarm) is a significant source of human body odor and has been described as the most "powerful and distinctive" of all human body odors (Takeuchi, Yabuki, & Hasegawa, 2013, p. 223). Axillary sweat is initially odorless but can become odorous through the bacterial metabolism of products present in sweat (Shelley, Hurley, & Nichols, 1953). Significant quantities of liquid sweat can be generated during exercise (Manshahia & Das, 2014), and this sweat can transfer from the body to adjacent clothing; thus, it is common for clothing to pick up axillary odors. Many consumers have reported problems with odor on clothing used for exercising. Furthermore, some odor within clothing has been described as being even more intense than the original source (i.e., axilla) (Dravnieks, Krotoszynski, Lieb, & Jungermann, 1968). Clothing fiber content plays an important role in how intense axillary odor becomes following wear. Researchers have shown that odor within polyester fibers is significantly more intense than odor within cotton and wool fibers (McQueen, Laing, Brooks, & Niven, 2007a). Polyester is a synthetic fiber characterized as being nonpolar and subsequently hydrophobic; it is the most dominant fiber used in sportswear apparel (Shishoo, 2015). Nylon is another common synthetic textile fiber exhibiting many of the same benefits as polyester (e.g., ability to manipulate the fiber structure to enhance wicking, quick drying). However, nylon is less hydrophobic than polyester, with a moisture regain of 4.5% at 20 °C and 65% relative humidity (R.H.) compared with 0.4% for polyester (Canadian General Standards Board, 2001). McQueen, Laing, Delahunty, Brooks, and Niven (2008) compared merino wool, cotton, and polyester fabrics and showed a relationship between the ability of a fabric to absorb moisture with its propensity to absorb and/or emit odor. To date, there are no reports of trials evaluating the odor intensity of nylon following wear next to the axillary region in comparison to other fabrics.

The current study was designed to determine whether odor intensity on nylon fabrics differed from odor intensity on polyester fabrics. As no laboratory tests exist which can suitably mimic the process of how human body odors are generated, transferred, and subsequently emitted from clothing, a wear trial was carried out in order to collect axillary odor on nylon and polyester fabrics. As the human nose can capture the overall axillary bouquet and assign a single measurement rating such as “intensity” to it, this makes it an appropriate measurement tool. Therefore, odor was detected using a sensory panel of 13 assessors. The wear trial was compared to a standard test method to evaluate the odor absorption of two volatile compounds (International Organization for Standardization, 2014). A secondary purpose of this study was to determine the effect that two types of storage conditions (freezing versus stored at room temperature) had on odor intensity.

Background

Odor Retention in Fabrics

Researchers have shown that odor intensity released from clothing, following wear next to the skin, can differ considerably due to the generic fiber content from which the fabric is made (McQueen et al., 2007a; Munk, Johansen, Stahnke, & Adler-Nissen, 2001). Knit fabrics that varied by fiber type (merino wool, cotton, polyester) and fabric structure (interlock, 1x1 rib, single-jersey) were worn next to the axillary region of male participants. A panel of assessors perceived the intensity of odor on wool fabrics to be significantly lower than on cotton fabrics, which were significantly lower than on polyester fabrics (McQueen et al., 2007a). There were no differences found between the bacterial populations on the test fabrics one day after wear; however, as fabrics were stored, the counts of viable bacteria remaining on polyester fabrics declined at a faster rate than bacteria on cotton and wool. After 28 days of wear, merino wool fabrics had significantly higher counts of bacteria than polyester did. In another study, researchers found there to be selective growth of *Micrococcus* species in polyester (but not on cotton) clothing following exercise (Callewaert et al., 2014). How axillary odor is retained and released by textiles is a complex phenomenon; little is understood about what mechanisms are at play to make some fabrics more odorous than others. Bacteria may create the odor in the first place, and some selective growth on different textile fibers can occur, but when assessing odor that has been transferred from the body to the clothing, the chemical and physical properties of the generic fibers play a more significant role. The ability to chemically bind odorants within the fiber structure itself may be very important.

Selective sorption and release of volatile compounds (odorous and non-odorous) can differ depending on the fiber content of the fabric. Researchers comparing the chemical odor profiles of cotton and polyester fabrics following contamination with male sweat found that polyester had a much more diverse range of high-impact odorants than cotton (Munk et al., 2001). Furthermore, washing removed odorants more effectively from cotton than from polyester (Munk et al., 2001). McQueen, Harynuk, Wismer, Keelan, Xu, and de la Mata (2014) found higher concentrations of carboxylic acids in the headspace above polyester fabric when compared to cotton fabric after wear. In subsequent analysis of the same fabrics, de la Mata, McQueen, Nam and Harynuk (2017) were able to distinguish between cotton and polyester fabrics based on their selective sorption of semi-volatile compounds. In a study on the profiles of volatiles released in the headspace from four different fabrics (cotton, polyester, wool, and rayon), Prada, Curran, and Furton (2011) noted that the different fabrics selectively retained and released compounds based on various chemical classes.

McQueen et al. (2008) observed a negative correlation between moisture regain and odor intensity for wool, cotton, and polyester fabrics; they found that as the moisture regain increased, the perceived odor intensity decreased. This highlights a relationship that may exist between the fiber's ability to absorb moisture vapor and the ability to absorb odorous volatile compounds from the environment. If the volatile compounds are trapped within the fiber, then the nose perceives less odor. Activated carbon, perhaps one of the best known materials with the capacity to sorb many liquids and gases within its porous structure, is used in many applications for odor control (Dohmae et al., 2008; Eza, Ahmad, & Ahmad, 2012).

Nylon and Polyester Fibers

Moisture management has been described as the most important factor in sportswear comfort as it plays a key role in both sensorial and physiological comfort in sportswear (Brotherhood, 2008; Morrissey & Rossi, 2013). Synthetics are widely used in sportswear because of their ability to manipulate the fiber structure to create capillary pathways and pores, which enable effective wicking of liquid moisture (Roberts, Waller, & Caime, 2007). Manshahia and Das (2014) reported that fiber-liquid transport is higher in sportswear knitted with polyester composed of filament fibers/yarns. Nylon is another synthetic fiber with superior moisture transport properties. It is the second most widely used synthetic in sportswear (Kothari, 2008). Polyester fiber is a manufactured fiber "composed of linear macromolecules having, in the chain, at least 85% by mass of an ester of a diol and terephthalic acid" (International Organization for Standardization, 2013, p. 7). The most common form of polyester fiber is polyethylene terephthalate, which is produced by a reaction of terephthalic acid or dimethyleterephthalate with ethylene glycol (East, 2005). Polyester is nonpolar and aliphatic, with no available groups for making hydrogen bonds. Therefore, polyester fabrics are characterized by low moisture regain (0.4% in 65% R.H.) and with problems such as the buildup of electrical charges, retention of soils (especially oily soils), and other difficulties associated with laundering (East, 2005).

Nylon (polyamide) fiber is also a manufactured fiber "composed of linear macromolecules having in the chain recurring amide linkages, at least 85% of which are joined to aliphatic or cycloaliphatic units" (International Organization for Standardization, 2013, p. 7). The two most important types of nylon used in apparel are nylon-6 and nylon-6,6. Nylon-6 is produced by the self-condensation of caprolactam and nylon-6,6 is produced through the interaction of hexamethylene diamine and adipic acid (Cook, 2001). Nylon, like polyester, is semi-crystalline, characterized by both amorphous and crystalline states throughout the fiber, with van der Waal's and (unlike polyester) hydrogen bonds as intermolecular forces. Hydrogen bonds involve the amine and carboxylic moieties, and are important in denoting strength to the fiber, but also are sites for water sorption (Yang, 2007). Nylon has a moisture regain of 4.5% at 20 °C and 65% R.H., so although more hydrophobic than natural fibers, it is the most hydrophilic of the synthetic fibers. This is because the amide groups can form hydrogen bonds with water (Richards, 2005). Water can reduce the glass transition temperature (T_g) of nylon considerably. At 85% R.H. the T_g can be reduced to room temperature (Richards, 2005). This plasticizing effect that water can have on nylon fibers may increase its likelihood of absorbing polar acidic compounds (and other polar compounds) known to be present in axillary odor. In wool, the rate of sorption of acetic acid was found to increase as the relative humidity increased from 20% R.H. to 80% R.H. (Pucher, 1971), which could be explained by the plasticizing effect of moisture on wool (McQueen et al., 2008). A similar effect may occur for nylon fabrics as more amide groups may become available for bonding with polar molecules with increasing humidity. The research hypothesis was that nylon fabrics would be significantly lower in odor intensity than polyester fabrics.

Storage Conditions on Odor

The numerous studies on evaluating odor after collecting human axillary odors onto fabrics or pads were primarily done with cotton or regenerated cellulose. The authors of these studies have focused on discrimination among individuals; odor recognition of gender, kin, or partners; attractiveness of the opposite sex; or perception of emotional responses (Ackerl, Atzmueller, & Grammer, 2002; Wedekind, Escher, Van de Waal, & Frei, 2007). Collecting odor samples can be onerous for the participants, who may be required to follow specific hygiene and dietary routines (Ferdenzi, Schaal, & Roberts, 2009). In order to minimize changes that may occur due to microbial action, samples may be evaluated a few hours after the odor has been collected, or samples are frozen prior to evaluation. Lenochova, Roberts, and Havlicek (2009) conducted two experiments to evaluate the effect that freezing the samples had on quality and intensity of the odor, and whether multiple freeze-thaw cycles had an effect on odor. The researchers found that, when compared to fresh odor samples, odor quality and hedonics (i.e., pleasantness) were not affected by freezing. However, a significant reduction in intensity was noted for essences applied to fabrics, and a significant increase in odor intensity was observed for axillary samples after the samples had been twice frozen and thawed (Lenochova et al., 2009).

Freezing samples between odor collection and odor evaluation has not typically been carried out when the purpose of the research has been to compare odor intensity on different types of fabrics. McQueen et al. (2007a) evaluated axillary odor intensity on nine different fabrics one day, seven days and 28 days after wear; fabric specimens were stored at 20 °C at 40% or 60% relative humidity. No statistical differences were found in odor intensity between the three time periods. However, since the same fabric samples were evaluated at each time interval, it was not possible to conduct a direct comparison among the three sessions. Munk et al. (2001) also did not freeze samples between odor collection and odor evaluation.

Airing clothing could be viewed as a method for deodorizing it, but odor could also intensify on clothing with time, as bacteria continue to metabolize sweat and thus intensify odor. How odor changes on clothing between wear and washing could be fiber-specific. For example, McQueen et al. (2008) identified compounds, likely to be short-chained carboxylic acids, in higher concentrations after seven days following wear on polyester fabrics. This increase was not observed on wool or cotton fabrics (McQueen et al., 2008). The research hypothesis was that a significant difference in odor intensity would be detected following storage at room temperature when compared with samples that had been frozen.

Method

Fabric Selection and Preparation

Four fabrics were selected for this study: two nylon and two polyester fabrics (see Table 1). To minimize the effect that different finishing and dyeing processes on fabrics may have on odor retention, the fabrics were purchased from TestFabrics Inc. (West Pittston, PA), where minimal finishing treatments are conducted. The fabric pairs consisted of one nylon fabric and one polyester fabric matched by the fabric structure (i.e., weave and knit). The fabrics were grouped into these two sets of fabric pairs in order to match the fabrics by structure and other physical properties as closely as was practicably possible. Fabrics were washed five times using Tide® Free and Gentle fragrance-free detergent based on the protocol CAN/CGSB-4.2, No. 58-2004 (Canadian General Standards Board, 2004). The fabrics were washed to reduce the likelihood of odor from “as received” fabrics. Fabric swatches (20 cm x 20 cm) were cut from the fabrics; woven fabrics were over-locked to prevent fabric fraying. The fabric pairs, nylon and polyester, were sewn into the underarm region of a 100% cotton T-shirt, and were randomly assigned to either the left or right side of the body.

[Insert Table 1 about here]

Research Approach

This study was conducted as a wear trial where participants wore fabric swatches (sewn into T-shirts) next to the axillary region. A wear trial was deemed appropriate due to the complexity of how axillary odor is transferred and retained within fabrics, as it represents how odor is transferred in real life. The Human Research Ethics Board 2 at the University of Alberta approved all research protocols prior to the start of research with human participants.

Prior to selection for the wear trial, participants were screened to ensure they had sufficient odor intensity. The screening trial involved participants wearing a cotton T-shirt, which had polyester fabric swatches sewn into the underarm region, during at least one hour of physical activity (activity was of participant's own choice). The fabric swatches were removed from the T-shirts and later assessed by three experienced assessors for odor intensity. Participants were assessed for strong left/right odor imbalances, (a difference of 2 points on a 10-point category scale is allowable) (American Society for Testing and Materials, 2009).

Eight participants (four male, four female) with an age range of 18-45 years were accepted for the study. Sample sizes of 5-10 are common in studies where the topic of investigation is body odorants or examination of skin microbiology (Curran, Rabin, Prada, & Furton, 2005; McQueen et al., 2007a; Troccaz, Starkenmann, Niclass, van de Waal, & Clark, 2004). The participants were asked to either wear T-shirts/fabrics for one hour of vigorous exercise or for a full 12-hour day of low levels of physical activity. The goal of the wear trial was to generate sufficient odor so that it would be transferred to fabric worn next to the underarm region. As axillary odor can vary greatly among individuals in quality and intensity, the type of activity was not deemed to matter since the nylon and polyester fabrics within the same fabric pair had been exposed to the same environment. Therefore, the independent variables were fiber type (nylon and polyester), storage condition (room temperature and frozen), and participant (as a random factor). The dependent variable was odor intensity as rated on a 150 mm line-marking scale.

Wear Trial

Four participants (F1, M1, M2, M3) carried out a minimum of one hour of exercise (high level of sweating) and four participants (F2, F3, F4, M4) wore the T-shirts during their normal daytime activity for a 12-hour period that did not involve excessive sweating. All participants were asked to refrain from using antiperspirants, deodorants, or other cosmetic or antibacterial products in the underarm region two days prior to beginning the first T-shirt wear and until all T-shirt wears had been completed. They were also asked to avoid swimming in a chlorinated pool, and to avoid spicy food, including garlic and onions, 48 hours before and during each T-shirt wear.

After T-shirts were worn and returned, fabric swatches were removed from the T-shirts and cut into smaller fabric specimens (18 mm x 18 mm). Small fabric specimens were grouped together into two groups of 16 following a sampling procedure similar to that described in McQueen et al. (2007a). The two groups of specimens were: i) stored in a freezer (F) at -20 °C; and ii) stored at room (R) temperature (20 °C and 65% R.H.) for one week prior to sensory analysis.

Sensory Analysis

Sensory evaluation is the scientific discipline used to evoke, measure, analyze, and interpret reactions to characteristics of products as they are perceived by the senses of sight, smell, taste, touch, and hearing (Stone & Sidel, 2004). Sensory measurement is an important tool despite difficulties associated with human variation. In the analysis of axillary odorants on textiles, sensory measurement is highly appropriate. Ultimately, it is because the human nose detects odor in clothing that odor emanating from clothing is considered a problem in the first place. Thirteen assessors (12 females, one male; age range 18-45 years), screened for their olfactory acuity, were trained in odor intensity ratings according to Section 7 “Assessor Selection and Training” of ASTM E1207-09 (American Society for Testing and Materials, 2009).

Two to three hours prior to sensory analysis, the two groups of fabric specimens (frozen [F] and room [R]) were placed in amber wide-mouth bottles (120 mL in volume) and lids were screwed on to prevent loss of volatiles. Isovaleric acid solution, which was used in training, was inoculated onto a polyester fabric to serve as a low reference for the panel during the assessment of the samples. The samples, together with the reference sample, were placed in a water bath at 36-38 °C and presented to the sensory panel following the Latin square design in standard sensory testing rooms (International Organization for Standardization, 2007) at 21 ± 2 °C. The sensory panels were conducted over four separate test days, with a maximum of 12 test samples presented at one time. The assessors were asked to sniff the samples and rate the odor intensity by marking a vertical line on a 150 mm line-marking scale with an "extremely low" anchor on the left and an "extremely high" anchor on the right. Line marking requires assessors to rate a sensation by placing a mark on a line that has been anchored at each end point by some form of descriptor (e.g., weak/strong). Line-marking scales have a perceived advantage over category scales (e.g., 7-point Likert scale) in that the choices seem more continuous and less limited so potentially greater discrimination can be obtained (Lawless & Heymann, 2010). The line-marking scale (commonly used to rate attribute intensity by trained panels) is an appropriate tool for measuring intensity ratings in comparison to a simpler paired-comparison approach, as it allows for a magnitude of a difference to be determined (McQueen, Keelan, Xu, & Mah, 2013; McQueen, Laing, Wilson, Niven, & Delahunty, 2007b). Assessors were asked to take a 30-second break between each sample and to refresh the nose by sniffing distilled water (American Society for Testing and Materials, 2017). Scores were converted to a number by using a ruler to measure the distance from the left of the line to the vertical line marked by the assessor. Measurements were taken to the nearest 0.5 mm.

Odor Reduction Rate

The odor reduction rate (ORR) was calculated following ISO 17299-3 Method A (International Organization for Standardization, 2014). Isovaleric acid ≥ 98% (Sigma Aldrich) and 2-nonenal ≥ 95% (Sigma Aldrich) were used to represent compounds in body odor. The analysis was performed using a Gas Chromatography-Flame Ionization Detector (GC-FID) HP 6890 (Agilent Technologies, Santa Clara, CA, USA). The column used was a 30 m × 0.53 µm, 1 µm film thickness Restek Rxi-5MS (Chromatographic Specialties). Helium (5.0 grade; Praxair, Edmonton, AB) was used as the carrier gas with flow controlled at 2.5 mL/min. The samples were injected in the split/splitless injection port of the GC-FID using an inlet temperature set at 250 °C, operating in splitless mode. For nonenal, the oven temperature was set at 120 °C for 13 minutes, and for isovaleric acid the oven temperature was set at 70 °C for 12 minutes. The FID was set at 250 °C with an H_2 flow of 30.0 mL/min and air flow of 300 mL/min. Makeup helium flow was set at 20.0 mL/min. A 1 mL Hamilton gastight syringe (Fisher Scientific) was used to perform the injections. One mL of the headspace was injected to the GC-FID.

The odor reduction rate (ORR) was calculated using the following formula:

$$ORR = \frac{B-A}{B} * 100$$

Where: B is the average of the concentration of the testing gas without a specimen; and A is the average of the concentration with a specimen (International Organization for Standardization, 2014). The propagated error percentage was calculated for each value.

Statistical Analysis

The mean (M) and standard error of the mean (SME) of the assessors' ratings were calculated for each participant and each fabric. The intention was to use parametric statistics to analyze the data with a three-way analysis of variance (ANOVA), with fabric and storage as fixed factors and participants as a random factor. Parametric statistics are frequently applied to data obtained using category or line-marking scales, assuming equal intervals (Lawless, Horne,

& Spiers, 2000; Villarino, Dy, & Lizada, 2007). However, it can be argued that meeting the underlying statistical assumptions, such as normal distribution and equal variance, is more important than whether data is interval or ordinal (Gaito, 1980). If there is doubt about the statistical significance, from applying parametric statistics to data from category or line-marking scales, data can be reanalyzed using nonparametric statistics in an effort to avoid faulty conclusions (Lawless & Heymann, 2010). Therefore, the data from each fabric pair (i.e., Pair 1: N1 and P1; Pair 2: N2 and P2) were analyzed by the Friedman test for all participants combined and also separately for each individual participant. Where significant differences were found in the Friedman test, a post-hoc Wilcoxon signed-rank test was carried out. The Friedman and the Wilcoxon tests are non-parametric equivalents of a one-way ANOVA and paired t-test, respectively, and were deemed to be more appropriate as the data did not fit the assumptions of normality and equal variance required for parametric tests.

To account for the multiple (six) paired comparisons in the Wilcoxon post-hoc tests, a Bonferroni correction was carried out, and significance was taken when the p-value was less than or equal to 0.008 rather than 0.05 (Kaltenbach, 2012). All statistical analysis was carried out using SPSS Version 23.

Results and Discussion

Effect of Fiber Content

A summary of the overall means in odor intensity, for all participants combined, is shown in Table 2. Fiber type differences are only evident with a larger difference in nylon odor intensity for Pair 1 fabrics, after storage at room temperature, with mean odor intensity ratings of 40.14 (± 14.35) compared to 26.19 (± 4.36) for nylon and polyester, respectively. In all other fabric pair/storage conditions, the mean odor intensities did not differ (e.g., frozen condition: N2 = 33.76 ± 14.39; P2 = 31.35 ± 16.60).

[Insert Table 2 about here]

The odor intensity ratings for separate individuals for Fabric Pair 1 (N1, P1) and Fabric Pair 2 (N2, P2) for both storage conditions (frozen [F] and room temperature [R]) are shown in Figures 1 and 2, respectively. No apparent trend for either fabric pair, where one fabric was perceived to be consistently lower than the other in odor intensity, appeared to be occurring. For example, in the frozen storage condition, the N1-F fabric had a higher mean rating than the P1-F fabric for four participants (F1, F2, F4, M1), and for the other four participants, P1 was rated higher in odor intensity than N1 (Figure 1). For Fabric Pair 2, N2-F had a higher mean rating than P2-F for four of the participants (F1, F2, F3, M2) (Figure 2).

[Insert Figures 1 and 2 about here]

The mean ranks of odor intensity ratings and the levels of significance for individual participants are shown in Table 3. Only a few of the fabric pairs resulted in statistical differences. For Fabric Pair 1, a significant difference was found among the fabric/storage combinations when all participants were combined ($\chi^2 = 43.233$, $p < 0.001$) (see Table 3). The rating for nylon stored at room temperature was significantly higher than for all other fabrics. For individual participants, significant differences were found for three of the eight participants (F2, M2, M4), although the highest ranked N1-R fabric was significantly higher than P1-R for two participants (F2, M2). The nylon fabric worn by Participant M4 and stored at room temperature (N1-R) had a much higher rating than the corresponding polyester fabric (P1-R). However, when the Bonferroni correction was applied requiring $p \leq 0.008$ to be met, it was not considered statistically significant ($Z = -2.000$, $p = 0.046$). It is still important to note that of 12 assessors, 10 rated the nylon fabric to be higher in odor intensity than the polyester. N1-F was also significantly higher than P1-F for Participant F2 ($Z = -2.706$, $p = 0.007$).

[Insert Table 3 about here]

For Fabric Pair 2, there were no significant differences among any of the fabric/storage combinations when all participants were combined ($\chi^2 = 4.676$, p = 0.197) (see Table 3). Statistical differences were found for four individual participants (F1, F4, M2, M4). However, only differences between fabric type (when keeping storage condition constant) were apparent for M2 after frozen storage (Z = -2.900, p = 0.004) and room temperature (Z = -3.180, p = 0.002), and Participant F4 for fabrics stored at room temperature (Z = -2.903, p = 0.004). Only in one case was nylon statistically higher in odor intensity than the matched polyester fabric. Based on these results, the hypothesis that nylon fabrics would be lower in odor intensity following wear next to the axilla was not supported.

Since nylon has polar groups in its chemical structure, and therefore the capacity to absorb moisture (evident by its much higher moisture regain), it was hypothesized that more odorous polar compounds, which constitute much of the axillary bouquet, would be absorbed within the fiber and subsequently trapped so as to not be perceived in the headspace above the fabric. The ORR was higher for nylon fabrics compared to the matched polyester fabrics for both chemical compounds (see Table 4). For example, the ORR for isovaleric acid was 63% and 79% for N1 and N2, respectively, compared with 17% and 23% for P1 and P2, respectively. Therefore, the ORR would also indicate that nylon should be perceived to be less odorous than polyester, as greater absorption by the nylon fabrics of the isovaleric acid (polar) and nonenal (nonpolar) was evident. Yet, the results from the wear trial show that nylon was not perceived to be less odorous than polyester overall. In fact, in most of the cases where differences were significant, nylon was perceived as the most intense fabric rather than polyester.

[Insert Table 4 about here]

The researchers conducting this study are the first to compare nylon and polyester fabrics for retention of axillary odor. Researchers in one study did examine a method to control odor on nylon fabrics by treating them with an antimicrobial (Mao & Murphy, 2001), but no comparisons with polyester fabrics were made. Bowers and Chantrey (1969) discuss the importance of a fiber's hydrophobic-hydrophilic characteristics in relation to soiling. They show that soiling propensity increases rapidly as the fiber moisture regain decreases, and that 4% regain is the critical point at which soiling rapidly increases (i.e., below this value). The hydrophobic characteristics of polyester should increase its capacity to absorb and retain oily soils from human skin, some of which would provide the necessary nutrients for bacteria to metabolize and generate odor. This selective sorption was shown by the chemical analysis, with higher sorption by polyester fabrics of the nonpolar nonenal compared with the polar isovaleric acid. The fabrics in the current wear trial were worn against the underarm for a relatively short period of time, and therefore, the buildup of odor over multiple uses, similar to the study carried out comparing cotton and polyester (McQueen et al., 2014), may result in more distinct differences in odor. This may be due to the fact that nylon fabrics would release soils more readily during washing than polyester (Fort, Billica, & Grindstaff, 1966).

In both fabric pairs, the nylon fabric was heavier than the polyester fabric, and this might explain why nylon was not lower in odor than polyester. Nylon has a lower specific gravity than polyester (Deopura, 2008; East, 2005), so the fiber is lighter. Although it was not measured in this study, based on fabric density and specific gravity, the surface area of the nylon would have been larger than that of the polyester, and as such the capacity for adsorbing compounds onto the surface would have been greater. Fabric density was not found to be an influencing factor of odor intensity in fabrics that emitted low axillary odor, such as cotton and wool fabrics (McQueen et al., 2007a). However, the thinner, lighter-weight, single-jersey polyester fabrics were perceptibly lower in odor intensity than the heavier-weight 1x1 rib and interlock constructions (McQueen et al., 2007a). The authors postulated that for high odor-emitting fabrics, structural differences that affect physical properties of the fabrics might have an impact on how odorous the fabric can become, whereas, for low odor-emitting fabrics, fabric physical properties could be less influential.

As the intensity emitted from the fabrics was not perceived overall to be significantly different, it is possible that a left/right odor imbalance may explain some of the differences that were observed between fabrics. For example, for Participant M1, the Fabric Pair 1 nylon fabric (N1) was perceived as more odorous than polyester (P1); for Fabric Pair 2, where the polyester and nylon fabrics were switched to opposite sides of the T-shirt, the nylon fabric (N2) was perceived as less odorous than polyester (P2). Differences in odor between the left and right side of the body are generally non-significant, so the sides can be considered the same in terms of odor collection (Ferdenzi et al., 2009).

Effect of Storage Conditions

In terms of storage conditions, the nylon fabric in Fabric Pair 1 had higher overall mean odor intensity ratings at room temperature than when frozen (Table 2). That is, the odor intensity was perceptibly higher for room-stored fabrics than for frozen fabrics. The nylon stored at room temperature had a mean odor intensity rating of 40.14 (± 14.35) compared to 28.08 (± 14.17) for nylon stored in the freezer. No perceptible differences in odor intensity between storage conditions were found for any of the Fabric Pair 2 fabrics.

Despite a general trend of odor intensity ratings increasing, there were still only a few cases where statistical differences were found. Significant differences between storage conditions for nylon fabrics in Fabric Pair 1 were evident for Participant M1 ($Z = -2.726$, $p = 0.006$) and Participant M4 ($Z = -2.981$, $p = 0.003$). Polyester fabrics worn by Participant M1 also were significantly different, although the frozen polyester exhibited higher odor than the fabric stored at room temperature ($Z = -3.180$, $p = 0.002$). For Fabric Pair 2, statistical differences between the nylon fabrics stored at frozen and room temperature conditions were only found for Participant F3 (Z = -2.621, p = 0.008). Differences between storage conditions for polyester fabrics were found in Fabric Pair 2 for Participant F4 (Z = -2.981, p = 0.003), where polyester stored at room temperature was higher than the frozen polyester fabric.

For the nylon fabrics, where odor intensity was found to increase following storage at room temperature, there could be two explanations for what was happening. The frozen fabrics could be diminishing in odor intensity as a result of freezing; the odor on fabrics stored for one week at room temperature could be intensifying. Both could be occurring simultaneously. A major challenge in textile odor research, when handling fabric samples which have been worn next to the human body, is the potential for the odor to change as a result of volatilization, as some of the odorous compounds dissipate and reduce in intensity and/or microbial degradation, while other odorous compounds are produced and the odor intensifies. From the perspective of understanding more about the mechanisms of how odor is retained and released from apparel fabrics, both scenarios have very practical implications. For example, "airing" clothing could be one method used to reduce odor when the garments are not immediately laundered after wear. The moist microclimate within the "unaired" clothing (e.g., in a laundry pile or gym bag) could facilitate the growth of microorganisms that continue to produce odors. In research it is important to be able to capture the odor profile within a specific period of time following wear prior to sensory or instrumental analysis. Freezing samples has been the common approach to this as researchers have focused on mate preference, attractiveness, and hedonics of body odor (Lenochova et al., 2009; Rantala et al., 2006). Researchers found that odor quality and hedonics did not change as a result of freezing compared to "fresh" odor samples (obtained on cotton pads), yet there was a small impact on odor intensity (Lenochova et al., 2009). Some odor intensity may be lost as a result of freezing, and the frozen samples used in the current study may not be identical to the samples if they had been evaluated as "fresh" samples. However, it is difficult to know with certainty whether room-stored samples were intensifying or frozen samples were becoming less intense. Results from Fabric Pair 1 for Participant M1 are quite interesting, as the polyester fabrics became less intense following storage at room temperature, yet the nylon fabrics became more intense. Similarly, for Participant F1, there was an increase in intensity for the N1-R fabric compared to the N1-F fabric, but no difference was observed with the P1 fabric. The N1 fabric was heavier than the P1 fabric (218 g/m^2 and 190 g/m^2, respectively). Therefore, it is possible that the sorption capacity of precursors to odor compounds from axillary sweat may have harbored more bacteria for the generation of odor.

Limitations and Future Directions

This research is important because the authors are the first to address the topic of comparing odor retention among polyester and nylon fabrics. Although axillary odor retention and buildup within polyester fabrics have been identified as major concerns by textile manufacturers, clothing marketers, and consumers alike, nylon itself has been either overlooked or lumped together with polyester as "synthetics." Therefore, this study is only the beginning in understanding the impact nylon may have on odor buildup within clothing.

As a result of this study, we now raise a number of other questions that should be addressed in future research. The test fabrics selected from this study were purchased from TestFabrics Inc., so were undyed and exposed to minimal finishing treatments. As such, they do not represent the commercial fabrics used in sportswear apparel. Determining the effect that dyes and other finishing treatments, unique to the two generic fiber types, have on odor retention is one direction for future research. Both nylon fabrics were nylon 6,6, so a comparison to nylon 6 fabrics may yield different results. Matching the fabrics more closely in fabric density may also result in differences in odor intensity. Chemical analysis, coupled with sensory detection, such as gas chromatography-olfactometry (GC-O), would be useful to determine the key chemical odorants retained and then released from nylon and polyester fabrics.

Human participants as T-shirt wearers (odor providers) and as assessors (odor detectors) play an essential role in the measurement of differences among fabrics following wear against the axilla. Humans are highly variable sources of odor, which can lead to variable and conflicting results; controlled laboratory studies that can independently examine a range of chemical odorants, as well as investigate the precursors to odor in combination with odor-causing bacterial species, are required. Standard laboratory tests that can be used to predict the way in which odor develops within a textile fabric, effectively simulating how odor is transferred and generated within clothing fabrics during real-use circumstances, do not yet exist.

Conclusions

The purpose of this study was to compare the odor intensity of nylon and polyester fabrics following wear against the axillary region, as well as to evaluate how storage conditions affected odor intensity. It was hypothesized that nylon would be less odorous than polyester fabrics due to its higher moisture regain, as previous researchers studying wool, cotton, and polyester fabrics found moisture regain was negatively correlated with odor intensity (McQueen et al., 2008). It was evident from this wear trial that nylon fabrics can hold and retain odor after being worn next to the axilla. It was also apparent that there was no difference (overall) in odor intensity of nylon fabrics compared to polyester fabrics, and for some individuals the nylon fabrics were significantly more odorous than polyester fabrics. The ORR also showed that nylon fabrics were more absorbent of odorous chemical compounds compared with polyester fabrics.

The approach to evaluate odor intensity through the use of human participants both as odor providers and odor assessors was appropriate, as odor generated on the human body and then transferred to clothing (where more odor may still be produced) is a highly complex phenomenon. The ORR did not predict axillary odor intensity of clothing following wear, which may be due to the oversimplification of a complex problem. That is, odor-causing bacteria, sweat (precursor to odor), and odorous products themselves are all transferred to clothing during wear, while further odor may be generated within the fabric. Sensory assessment is both relevant and applicable as a tool to measure odor intensity. There was some evidence to suggest that odor intensity could increase on nylon fabrics when stored at room temperature, but this was less apparent for polyester fabrics. This may also be dependent on the specific nylon fabric and the individual who wore the fabric.

References

Ackerl, K., Atzmueller, M., & Grammer, K. (2002). The scent of fear. *Neuroendocrinology Letters*, *23*(2), 79-84.

American Society for Testing and Materials. (2009). *ASTM E1207: Standard Guide for Sensory Evaluation of Axillary Deodorancy*. West Conshohocken, PA: ASTM International.

American Society for Testing and Materials. (2017). *ASTM E1871-17: Serving Protocol for Sensory Evaluation of Foods and Beverages*. West Conshohocken, PA: ASTM International.

Bowers, C. A., & Chantrey, G. (1969). Factors controlling the soiling of white polyester cotton fabrics. *Textile Research Journal*, *39*(1), 1-11.

Brotherhood, J. R. (2008). Heat stress and strain in exercise and sport. *Journal of Science and Medicine in Sport/Sports Medicine Australia*, *11*(1), 6-19.

Callewaert, C., De Maeseneire, E., Kerckhof, F.-M., Verliefde, A., Van de Wiele, T., & Boon, N. (2014). Microbial odor profile of polyester and cotton clothes after a fitness session. *Applied and Environmental Microbiology*, *80*(21), 6611-6619.

Canadian General Standards Board. (2001). *CAN/CGSB-4.2 No. 0-2001 Textile Test Methods: Moisture Regain Values, SI Units Used in CAN/CGSB-4.2 and Fibre, Yarn, Fabric,* *Garment and Carpet Properties*. Ottawa, ON: CGSB.

Canadian General Standards Board. (2004). *CAN/CGSB 4.2 No. 58-2004 Textile Test Methods - Dimensional Change in Domestic Laundering of Textiles*. Ottawa, ON: CGSB.

Cook, J. G. (2001). *Handbook of textile fibres. Vol. II - Man-made fibres*. Cambridge, England: Woodhead Publishing Limited.

Curran, A. M., Rabin, S. I., Prada, P. A., & Furton, K. G. (2005). Comparison of the volatile organic compounds present in human odor using SPME-GC/MS. *Journal of Chemical Ecology*, *31*(7), 1607-1619.

de la Mata, A. P., McQueen, R. H., Nam, S. L., & Harynuk, J. J. (2017). Comprehensive two-dimensional gas chromatographic profiling and chemometric interpretation of the volatile profiles of sweat in knit fabrics. *Analytical and Bioanalytical Chemistry*, *409*(7), 1905-1913.

Deopura, B. L. (2008). Polyamide fibers. In B. L. Deopura, R. Alagirusamy, M. Joshi, & B. Gupta (Eds.), *Polyesters and polyamides* (pp. 41-61). Cambridge, England: Woodhead Publishing Limited.

Dohmae, S., Okubo, T., Higuchi, W., Takano, T., Isobe, H., Baranovich, T.,Yamamoto, T. (2008). Bacillus cereus nosocomial infection from reused towels in Japan. *Journal of Hospital Infection*, *69*(4), 361-367.

Dravnieks, A., Krotoszynski, B. K., Lieb, W. E., & Jungermann, E. (1968). Influence of an antibacterial soap on various effluents from axillae. *Journal of the Society of Cosmetic Chemists*, *19*(9), 611-626.

East, A. J. (2005). Polyester fibres. In J. E. McIntyre (Ed.), *Synthetic fibres: Nylon, polyester, acrylic, polyolefin* (pp. 95-166). Cambridge, England: Woodhead Publishing Limited.

Eza, T. S. M., Ahmad, W. Y. W., & Ahmad, M. N. (2012). The activated carbon as anti-odour coated and pigment printed fabric. *2012 IEEE Business, Engineering & Industrial*

Applications Colloquium (BEIAC), 210-215.

Ferdenzi, C., Schaal, B., & Roberts, S. C. (2009). Human axillary odor: Are there side-related perceptual differences? *Chemical Senses*, *34*(7), 565-71.

Fort, T., Billica, H. R., & Grindstaff, T. H. (1966). Studies of soiling and detergency. Part II: Detergency experiments with model fatty soils. *Textile Research Journal*, *36*(2), 99-112.

Gaito, J. (1980). Measurement scales and statistics: Resurgence of an old misconception. *Psychological Bulletin*, *87*(3), 564-567.

International Organization for Standardization. (2007). *ISO 8589:2007(E): Sensory analysis - General guidance for the design of test rooms*. Geneva, Switzerland: ISO.

International Organization for Standardization. (2013). *ISO 2076: Textiles - Man-made fibres - Generic names*. Geneva, Switzerland: ISO.

International Organization for Standardization. (2014). *ISO 17299-3: Textiles - Determination of deodorant property: Part 3 Gas chromatography method*. Geneva, Switzerland: ISO.

Kaltenbach, H. (2012). *A concise guide to statistics*. Heidelberg, Germany: Springer.

Kothari, V. K. (2008). Polyester and polyamide fibres – Apparel applications. In B. L. Deopura, R. Alagirusamy, M. Joshi, & B. Gupta (Eds.), *Polyesters and polyamides* (pp. 419-440). Cambridge, England: Woodhead Publishing Limited.

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: Principles and practices* (2nd ed.). New York, NY: Springer.

Lawless, H. T., Horne, J., & Spiers, W. (2000). Contrast and range effects for category, magnitude and labeled magnitude scales in judgements of sweetness intensity. *Chemical Senses*, *25*(1), 85-92.

Lenochova, P., Roberts, S. C., & Havlicek, J. (2009). Methods of human body odor sampling: The effect of freezing. *Chemical Senses*, *34*(2), 127-38.

Manshahia, M., & Das, A. (2014). Thermo-physiological comfort of compression athletic wear. *Indian Journal of Fibre & Textile Research*, *39*(June), 139-146.

Mao, B. J., & Murphy, L. (2001). Durable freshness for textiles. *AATCC Review*, *1*(11), 28-31.

McQueen, R. H., Harynuk, J. J., Wismer, W. V, Keelan, M., Xu, Y., & de la Mata, P. (2014). Axillary odour build-up in knit fabrics following multiple use cycles. *International Journal of Clothing Science and Technology*, *26*(4), 274-290.

McQueen, R. H., Keelan, M., Xu, Y., & Mah, T. (2013). *In vivo* assessment of odour retention in an antimicrobial silver chloride-treated polyester textile. *Journal of the Textile Institute*, *104*(1), 108-117.

McQueen, R. H., Laing, R. M., Brooks, H. J. L., & Niven, B. E. (2007a). Odor intensity in apparel fabrics and the link with bacterial populations. *Textile Research Journal*, *77*(7), 449-456.

McQueen, R. H., Laing, R. M., Delahunty, C. M., Brooks, H. J. L., & Niven, B. E. (2008). Retention of axillary odour on apparel fabrics. *Journal of the Textile Institute*, *99*(6), 515-523.

McQueen, R. H., Laing, R. M., Wilson, C. A., Niven, B. E., & Delahunty, C. M. (2007b). Odor retention on apparel fabrics: Development of test methods for sensory detection. *Textile Research Journal*, *77*(9), 645-652.

Morrissey, M. P., & Rossi, R. M. (2013). Clothing systems for outdoor activities. *Textile Progress*, *45*(2-3), 145-181.

Munk, S., Johansen, C., Stahnke, L. H., & Adler-Nissen, J. (2001). Microbial survival and odor in laundry. *Journal of Surfactants and Detergents*, *4*(4), 385-394.

Prada, P. A., Curran, A. M., & Furton, K. G. (2011). The evaluation of human hand odor volatiles on various textiles: A comparison between contact and noncontact sampling methods. *Journal of Forensic Sciences*, *56*(4), 866-881.

Pucher, M. (1971). Sorption of unpleasant odors by wool. *Applied Polymer Symposium*, *18*, 379-385.

Rantala, M. J., Eriksson, C. J. P., Vainikka, A., & Kortet, R. (2006). Male steroid hormones and female preference for male body odor. *Evolution and Human Behavior*, *27*(4), 259-269.

Richards, A. F. (2005). Nylon fibres. In J. E. McIntyre (Ed.), *Synthetic fibres: Nylon, polyester, acrylic, polyolefin* (pp. 20-94). Cambridge, England: Woodhead Publishing Limited.

Roberts, B. C., Waller, T. M., & Caime, M. P. (2007). Thermoregulatory response to base layer garments during treadmill exercise. *International Journal of Sports Science and Engineering*, *1*(1), 29-38.

Shelley, W. B., Hurley, H. J., & Nichols, A. C. (1953). Axillary odor. *Archives of Dermatology and Syphilology*, *68*(4), 430-446.

Shishoo, R. (2015). Introduction to textiles in sport. In R. Shishoo (Ed.), *Textiles for sportswear* (pp. 3-16). Cambridge, England: Woodhead Publishing Limited.

Stone, H., & Sidel, J. L. (2004). *Sensory evaluation practices* (3rd ed.). San Diego, CA: Elsevier Academic Press.

Takeuchi, K., Yabuki, M., & Hasegawa, Y. (2013). Review of odorants in human axillary odour and laundry malodour: The importance of branched C7 chain analogues in malodours perceived by humans. *Flavour and Fragrance Journal*, *28*(4), 223-230.

Troccaz, M., Starkenmann, C., Niclass, Y., van de Waal, M., & Clark, A. J. (2004). 3-Methyl-3-sulfanylhexan-1-ol as a major descriptor for the human axilla-sweat odour profile. *Chemistry & Biodiversity*, *1*(7), 1022-1035.

Villarino, B. J., Dy, L. M., & Lizada, M. C. C. (2007). Descriptive sensory evaluation of virgin coconut oil and refined, bleached and deodorized coconut oil. *LWT - Food Science and Technology*, *40*(2), 193-199.

Wedekind, C., Escher, S., Van de Waal, M., & Frei, E. (2007). The major histocompatibility complex and perfumers' descriptions of human body odors. *Evolutionary Psychology*, *5*(2), 330-343.

Yang, H. H. (2007). Polyamide fibers. In M. Lewin (Ed.), *Handbook of Fiber Chemistry* (3rd ed., pp. 31-137). Boca Raton, FL: CRC Press.

Table 1. Description of test fabrics

Pair	Fabric code	Fabric description	Mass per unit area (g/m^2)	Thickness (mm)	TestFabric code #
Pair 1	nylon [N1]	texturized nylon 6.6, double knit	218 ± 1.8	0.94 ± 0.02	314
	polyester [P1]	texturized polyester, double knit	190 ± 6.7	1.02 ± 0.02	720H
Pair 2	nylon [N2]	nylon 6,6 spun yarn, plain weave	204 ± 6.6	0.87 ± 0.01	365
	polyester [P2]	spun polyester type 54, plain weave	182 ± 2.1	0.85 ± 0.01	755

Table 2. Odor intensity ratings (Mean ± SD) from sensory panel for all participants combined

Pair	Fabric	Storage conditions	
		Frozen	Room
1	Nylon	28.08 ± 14.17	40.14 ± 14.35
	Polyester	25.85 ± 9.71	26.19 ± 4.36
2	Nylon	33.76 ± 14.39	34.28 ± 18.20
	Polyester	31.35 ± 16.60	34.73 ± 17.71

Table 3. Mean of rank order for fabric by storage conditions and level of significance

		Mean Rank				Friedman test results				
		Nylon		Polyester						
Pair	Participant	Frozen	Room	Frozen	Room	N	χ^2	df	Sig.	
1	ALL	2.26[a]	3.22[b]	2.30[a]	2.23[a]	102	43.233	3	0.000	***
	F1	1.77	3.00	2.38	2.85	13	7.440	3	0.059	
	F2	3.19[a]	3.62[a]	1.73[b]	1.46[b]	13	27.095	3	0.000	***
	F3	2.08	3.29	2.04	2.58	12	7.711	3	0.052	
	F4	2.42	2.92	2.12	2.54	13	2.756	3	0.431	
	M1	2.65[a]	3.85[b]	2.42[a]	1.08[c]	13	30.395	3	0.000	***
	M2	2.12	2.96	2.85	2.08	13	5.227	3	0.156	
	M3	1.92	2.54	2.69	2.85	13	3.921	3	0.270	
	M4	1.88[a]	3.58[b]	2.13[a]	2.42[a,b]	12	12.641	3	0.006	**
2	ALL	2.34	2.40	2.59	2.67	104	4.676	3	0.197	
	F1	2.23[a]	3.31[b]	1.62[a]	2.85[a,b]	13	12.692	3	0.005	**
	F2	2.54	2.04	2.23	3.19	13	6.118	3	0.106	
	F3	3.08	2.62	1.92	2.38	13	5.571	3	0.134	
	F4	1.73[a]	2.15[a]	2.38[a]	3.73[b]	13	19.578	3	0.000	***
	M1	1.92	3.04	2.23	2.81	13	6.209	3	0.102	
	M2	3.04[a]	3.73[a]	1.81[b]	1.42[b]	13	27.281	3	0.000	***
	M3	2.23	2.73	3.15	1.88	13	7.746	3	0.052	
	M4	1.92[a]	1.92[a]	3.08[a]	3.08[a]	13	10.385	3	0.016	*

*, **, *** Friedman's test was significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively; [a, b, c] Mean rank values followed by the same letter are not significantly different at $p < 0.008$ Wilcoxon ranked sign test

Table 4. Odor reduction rate (ORR) of isovaleric acid and 2-nonenal for nylon and polyester fabrics (%)

	Isovaleric acid		Nonenal	
	Nylon	Polyester	Nylon	Polyester
Pair 1	62.6 ± 32.2	17.2 ± 22.3	51.1 ± 11.8	36.8 ± 10.7
Pair 2	79.4 ± 3.1	32.2 ± 13.9	67.5 ± 5.4	38.9 ± 14.2

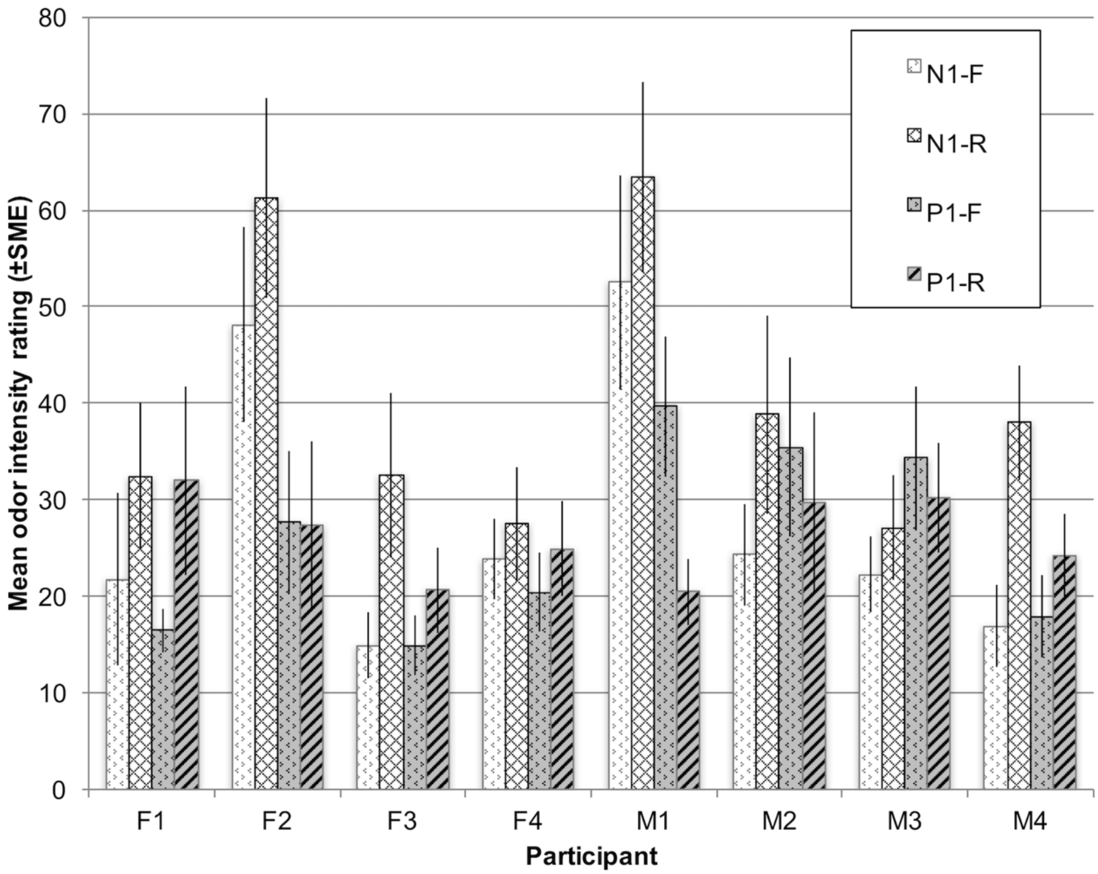

Figure 1. Sensory panel ratings for Fabric pair 1 (N1, P1) and effect of storage (F, R) for eight participants

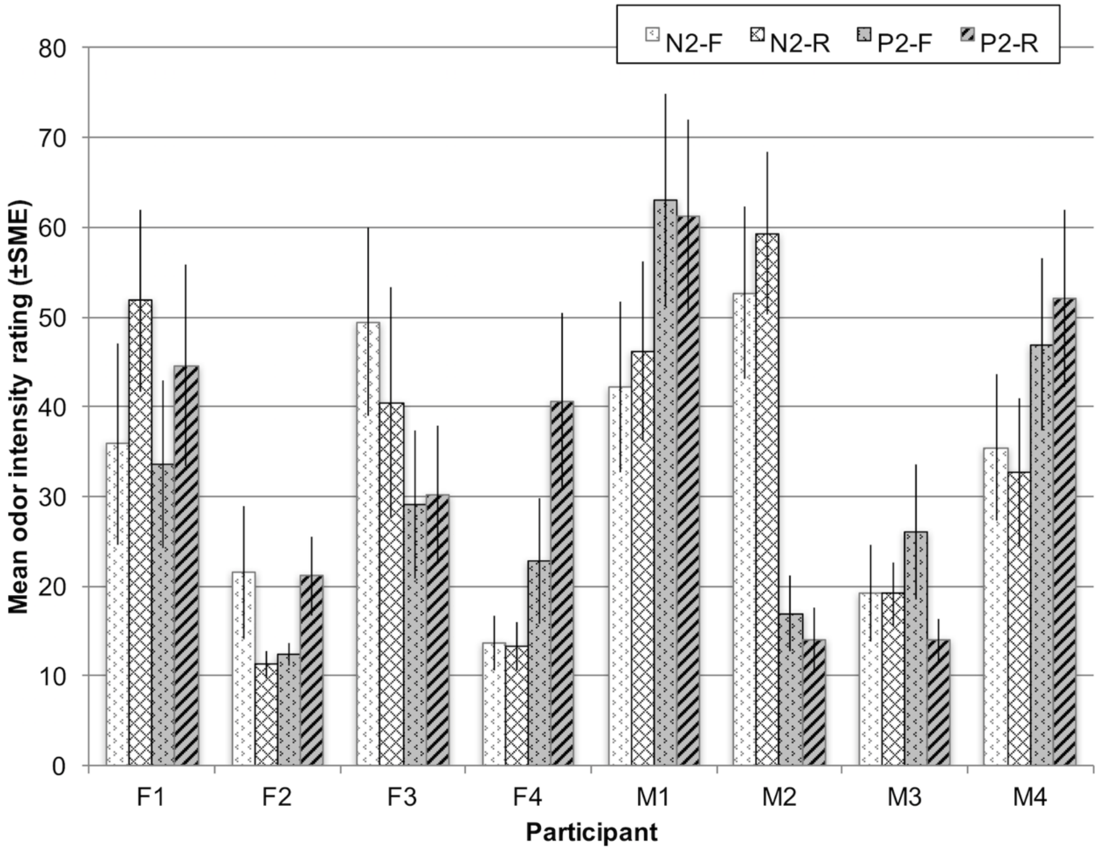

Figure 2. Sensory panel ratings for Fabric pair 2 (N2, P2) and effect of storage (F, R) for eight participants