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Product Comparison of Merino Wool and Polyester Baby Sleep Sacks

Dr S R Collie, Dr A Tasker and M F Hnat

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Executive Summary

This report presents the results of a baby sleep sack product comparison of the Merino Kids™ Newborn Sleep Bag and the polyester 'microfleece' Halo® SleepSack®. The Merino Kids newborn sleep sack is comprised of two layers of a flat-knitted superfine natural merino fabric, while the Halo sleep sack is a thicker three-thread synthetic fleece fabric (often referred to as 'polarfleece'). The comparison was of product properties that influence the thermophysiological comfort of sleeping infants, in other words how the products affect the ability of the baby's body to manage heat and moisture to maintain its normal thermal balance.

The sleep sacks are directly comparable as they are intended for the same use: i.e. designed to be worn by newborn babies over sleepwear to take the place of top sheets, blankets and comforters which can cover a baby's head. Head covering is identified as a risk factor of Sudden Infant Death Syndrome (SIDS) and the American Academy of Pediatrics recommends the use of baby sleep sacks as a safer alternative to loose bedding.

Anecdotal evidence from parents who use merino sleep sacks with their children suggests that merino offers very good thermophysiological comfort in use. Parents report that their babies sleeping in merino sleep sacks stay drier and sleep better through the night without becoming hot and sweaty. They comment that with polyester sleep sacks their babies had woken hot and clammy, and some developed heat rash. The issue of overheating the baby is of concern because the American SIDS Institute asserts that it may increase their risk of SIDS. This study seeks to quantify the properties of sleep sacks to confirm if the objective properties of the materials relate to the reported differences.

The growing interest in using natural products also favors merino over synthetic fiber types. Merino wool, as used in the Merino Kids sleep sack, is a naturally-sourced renewable fiber resource – re-growing on the sheep after shearing. Polyester microfleece is a synthetic material derived ultimately from non-renewable petrochemical sources.

The results of the product comparison indicate that the Merino Kids sleep sack is likely to be the best option for maintaining the baby's thermophysiological comfort and wellbeing in a wide range of conditions. In particular:

- The Merino Kids sleep sack was found to have moisture vapor absorption that is over 80 times higher than the Halo sleep sack. This means that the baby would be less likely to get damp (due to condensation of perspiration inside the sleep sack) in areas where moisture vapor transmission is restricted, such as between baby and mattress.

- The Merino Kids sleep sack has lower air permeability but the same moisture vapor transmission as the Halo sleep sack. This means that the baby is better protected from chilling due to unavoidable air movement from convection (loss of warm air around the body) and drafts, while still allowing moist air to be dispersed.

- The Merino Kids sleep sack has lower thermal resistance than the Halo sleep sack, but this is a result of its different fabric structure and not a fiber-related effect. The lower thermal resistance means that the baby is less likely to overheat in the Merino Kids sleep sack.

The high thermal resistance of the Halo sleep sack is only likely to be of value in stable cold environments. If the room temperature rises the Halo sleep slack might result in the baby becoming uncomfortably hot and damp because of its low moisture vapor absorption, whereas the better moisture management behavior of the Merino Kids sleep sack is likely to be beneficial to comfort in all circumstances, including nursery room temperature fluctuations and air movement from opening doors, windows, drafts and heating and cooling systems.

The scientific literature regarding sleeping comfort for adults and infants using wool bedding was also reviewed. In all pertinent trials the benefits of wool bedding were demonstrated, i.e. better temperature and moisture management under wool than under synthetic fiber products, leading to more restful sleep.

The above-mentioned thermophysiological comfort test results and sleeping comfort findings, combined with the low flammability, volatile absorption properties and non-irritant properties of merino wool indicate that it is the ideal fiber type to use in infant sleep sacks.

Contents

1. Introduction

Merino wool is undergoing a resurgence of consumer interest in markets where its intrinsic properties are appreciated. The recent emergence and popularity of merino-based next-to-skin, sportswear and children's wear products is testament to this, but there remain markets where merino's benefits are not yet appreciated. Merino products also tend to be more expensive than their competitors, which emphasizes the need for marketers to be able to provide the consumer with evidence of its technical advantages.

Many of these advantages are well understood in the scientific literature, but can be difficult for the consumer to grasp. In particular, the properties of textiles that relate to thermophysiological comfort (the ability of the body to manage heat and moisture to maintain its normal thermal balance) are complex, and often over-simplified for marketing purposes.

The ways in which merino wool affects comfort are quite sophisticated (largely because of the fiber's more complex interaction with moisture) so on the surface it can appear that synthetics have the advantage. On the other hand, anecdotal evidence from regular users of merino wool products suggests that wool has important comfort and performance advantages.

The purpose of this work was to compare the thermophysiological comfort properties of a merino sleep sack (Merino Kids™ Newborn Sleep Bag) with that of a polyester sleep sack (Halo® SleepSack®), and to interpret these results for the specific scenario of use for this type of product with the following question in mind: Which is better for babies? We also examined the existing scientific and technical literature for additional information relating to the properties of merino wool and synthetics in infant bedding and sleepwear applications. It is intended that the results of the research are able to be used for technical marketing of merino-based infant bedding and sleepwear.

The sleep sacks are directly comparable as they are intended for the same use: designed to be worn by newborn babies over sleepwear to take the place of top sheets, blankets and comforters which can cover a baby's head. Head covering is identified as a risk factor of Sudden Infant Death Syndrome (SIDS) and the American Academy of Pediatrics recommends the use of baby sleep sacks as a safer alternative to loose bedding [1]. Overheating the baby is also of concern as this may increase the risk of SIDS [2], further emphasizing the need to improve our understanding of how well baby sleepwear and bedding influence their thermophysiological comfort.

Note on terminology: Throughout this document the two products are referred to as 'Merino Kids' and 'Halo', and the term 'merino' is used to mean merino wool.

2. Methodology

Both specimens were tested as received, i.e. in the form they are presented in the garment. The tests were destructive, i.e. they required the garments to be cut into appropriate-sized samples for the different tests. All tests were carried out in standard conditions for textile testing, being 20°C (±2°C) and 65% (±5%) relative humidity [3]. Specimens were placed into this environment for at least 48 hours before tests were carried out.

2.1 Weight and thickness

Three square samples (100 mm x 100 mm, i.e. 0.01 m^2) of each fabric were prepared and then weighed in a conditioned environment using a balance, sensitive to at least three decimal places. The weights were then used to calculate the mass per square meter of each fabric. The thickness of each sample was determined using a Shirley Thickness Tester which provided the value in increments of tenths of a millimeter. Five measurements were averaged for each fabric.

Note: The term fabric 'weight' is used in this document (and throughout the textile industry) to refer to the 'weight per unit area' or 'areal density' of the fabric.

2.2 Thermal resistance and conductivity

Pre-cut circular test specimens of 330 mm diameter were tested according to WNZ TM 260 (based on BS 4745) [4], described briefly as follows.

The test specimen was placed on the bottom plate (hot plate) of the apparatus then the cold plate was placed on top of it at a height equal to the sample's thickness (so the top plate does not compress the fabric). The temperature of the hot plate was adjusted to 35°C. Temperatures are measured by thermocouples at the heater (T1), between the standard and the test fabric (T2) and between the fabric and the top plate (T3).

Temperature readings were made when thermal equilibrium was reached, i.e. the temperature remained steady at each thermocouple for a period not less than 30 minutes. The thermal resistance of the sample is given by the following equation:

$$Rs = \left(\frac{T2 - T3}{T1 - T2} \times Rst\right) - Rc$$

where: Rs = specimen resistance (m^2K/W)
Rst = standard resistance (known)
Rc = contact resistance (known)

A convenient unit used for thermal resistance is the 'tog' and 1 tog = 0.1 m^2K/W. Thermal conductivity can also be derived from these data, with units of W/m.K.

2.3 Moisture vapor transmission and absorption

Circular specimens (three for each fabric) were prepared (75 mm diameter), weighed and mounted into the lids of cylindrical pots. Each pot had 150 ml water added before the lid was attached and the entire pot (plus water and sample) was weighed. These were then left for 24 hours before the entire pot was reweighed followed by sample removal and further reweighing. From these data the moisture vapor absorption by the fabric (g/m^2) and transmission through the fabric (g/m^2) for each fabric were calculated.

2.4 Air permeability

Specimens were prepared (40 mm circles, five for each fabric) and then tested according to BS5636 (ISO 9237) [5]. Each sample was clamped onto the test holder and the flow of air was recorded. Readings were taken for both the face and back of each fabric. The average of these readings is given in units of ft^3/min/inch water/ft^2.

3. Results and Discussion

The results of the testing for both fabrics are summarized in Table 1, and these are discussed in the following sections. Complete data are provided in Appendix A.

Table 1. Test results for two commercial infant sleep sacks.

Test parameter	Product	
	Merino Kids™	Halo®
Thickness (mm)	2.12	3.65
Weight per unit area (g/m^2)	405	216
Thermal resistance (m^2K/W)	0.032	0.089
Tog rating	0.32	0.89
Thermal conductivity (W/m.K)	0.067	0.041
Moisture vapor absorption (g/m^2)	28.82	0.34
Moisture vapor transmission (g/m^2)	405.4	413.8
Air permeability ($ft^3/min/inch\ water/ft^2$)	167	393

3.1 Weight and thickness

Fabric weight and thickness reflect the differing fabric constructions of the two products. The Merino Kids sleep sack's higher weight and lower thickness are a result of it comprising of two layers of a flat-knitted plain single jersey fabric, while the Halo sleep sack is a lighter, thicker 'three-thread fleece' fabric (often referred to as 'polarfleece'). The density of the two fabrics can be calculated from these data, and for the Merino Kids sleep sack it is 0.191 g/cm^3, while for the Halo sleep sack it is 0.059 g/cm^3. These results further emphasize the fundamental difference between the two fabrics used: the very porous, lofty structure achieved by the three-thread fleece fabric used for Halo, and the more solid structure achieved by the single jersey fabric used for Merino Kids.

3.2 Thermal resistance and conductivity

The Merino Kids sleep sack has lower thermal resistance/tog rating and higher thermal conductivity than the Halo sleep sack. This is almost certainly simply an outcome of the higher thickness of that product, as thermal resistance in fabrics is largely a function of how much air is trapped, and a thick, lower density fabric contains more air than a thinner, denser fabric.

It is overly simplistic to focus on thermal resistance or tog rating alone. Tog is routinely used to specify simple bedding products for adults (e.g. blankets and comforters), but baby sleep sacks more closely resemble clothing, so other factors have significant influence. In a stable temperature cold room the higher tog rating of the Halo sleep sack would be valuable, but if the room temperature rises it might result in the baby becoming uncomfortably hot and damp because of its low moisture vapor absorption. These parameters are discussed in the following sections.

3.3 Moisture vapor transmission and absorption

Both fabrics have almost the same moisture vapor transmission (MVT), while the Merino Kids sleep sack has moisture vapor absorption (MVA) that is approximately 80-times greater than the Halo. The MVT result is noteworthy given the very much higher density of the Merino Kids sleep sack. This is explained by its far higher moisture vapor absorption and consideration of the mechanisms by which moisture vapor moves through a fabric.

Moisture vapor can pass through a fabric by moving directly through the empty spaces between fibers and yarns, but also through fibers by absorption (uptake) at the inner surface and desorption (release) at the outer surface. Both mechanisms operate for the Merino Kids sleep sack, while the non-absorbent nature of polyester means that only the former mechanism operates for the Halo sleep sack. Effectively the absorbent nature of merino wool compensates for the lower porosity of the Merino Kids fabric. If the Halo fabric was the same density as the Merino Kids fabric it would have very low MVT.

High MVT is beneficial to thermophysiological comfort as it helps to prevent high humidity under garments or bedding, which can lead to condensation of this moisture in the fabric or on the body. In this circumstance minor discomfort can result from clamminess, but it is possible for subsequent evaporation of the condensed liquid moisture to lead to chilling. Also, the presence of liquid moisture condensed in the fabric structure reduces the insulation properties of the fabric, by replacing highly insulating air with much less insulating water.

In situations where the outside environment is not conducive to MVT, such as when an impermeable outer layer is present, MVA becomes particularly important. If moisture cannot be transferred to the outside it must be absorbed into the fibers, or it will build up and condense as liquid. Considering the sleep-sack situation, there are no additional bedcovers used, so MVT is not restricted through the upper and side surfaces of the system. However, the cot or mattress restricts downward MVT, so the 80-times higher MVA of the Merino Kids sleep sack is likely to help maintain dryness and comfort under the baby.

3.4 Air permeability

Air permeability is the extent to which air can pass through a fabric. The Merino Kids sleep sack has 58% lower air permeability than the Halo sleep sack, as would be expected given its higher density. This lower permeability will help to reduce heat loss by convection, i.e. the upwards movement of warm air inside the garment away from the baby, passing through the fabric to the outside. It will also reduce the cooling effect of other air movement in the environment, such as drafts from opening doors and air conditioning.

3.5 Combined effects

As can be seen from the discussion above, the influence of the various factors can be complex, and when assessing the likely performance of an apparel or bedding system they should not be considered in isolation of other factors.

One particular combination of parameters that should be highlighted here is the combined effect of air permeability and moisture vapor transmission. It is notable that the Merino Kids sleep sack has high MVT yet low air permeability, while the Halo sleep sack has high MVT but with high air permeability. It appears that the Halo sleep sack is moisture vapor permeable simply because it is highly porous, whereas the Merino Kids sleep sack is less porous but still allows the transmission of moisture vapor. This intrinsic ‘breathability’ of the merino fiber, and hence the Merino Kids sleep sack, would better allow moist air to move away from the body’s micro-environment, preventing dampness and potentially chilling, while keeping the warm air around the body from escaping via convection.

4. Benefits of Wool – a Review of Literature

4.1 Influence of fiber type in bedding/sleepwear

To our knowledge there is no published study that directly compares the effect of wool-based bedcoverings or sleep apparel with other fiber types for infants. However, the sleeping comfort and behavior has been studied for wool bedding with adults, and separate research has examined the beneficial effects of wool pile fabrics (e.g. sheepskins) for babies. The outcomes of this research and several other relevant studies are reviewed in this section.

4.1.1 Bedding systems with adult subjects

We have identified three main studies that compared sleep behavior of wool bedding system with synthetics; two were carried out in the 1980s and published by the International Wool Secretariat (IWS), while the other was funded by Australian Wool Innovation (AWI) and published by The Woolmark Company in 2005.

In their 1984 publication [6] the IWS report on a study that compared equivalent wool and acrylic blankets, and equivalent wool and polyester-filled quilts (the blanket work was also reported in more detail in 1986 [7]). They used laboratory tests, an instrumented manikin and human trials to compare the blankets, but only laboratory tests for the quilts. They reported that the wool blankets had better heat and moisture transport properties in laboratory and manikin tests than acrylic (as would be expected as acrylic fibers have moisture absorbency properties closer to polyester than to wool), and the wool-filled quilt offered better 'moisture buffering' than polyester. Buffering refers to the ability of the textile system to moderate any change in the environmental temperature and/or relative humidity and maintain the subject's thermophysiological comfort.

In the human trials a relatively warm environment (23°C) was used (the study was intended to simulate conditions in which it was more likely that subjects could become uncomfortable), and it was found that the humidity and temperature at the body and in the bedding increased more over the course of the test for acrylic than for wool. This was borne out by the subjective ratings given by the participants: with acrylic 88% felt uncomfortably clammy and 75% uncomfortably hot while with wool these numbers dropped to 50% and 38% respectively. In both cases they are relatively high incidences of discomfort because of the warm environment used.

The heart rate and skin temperature of the sleeper, plus the humidity in the bed microclimate are considered to be good indicators of the comfort and restfulness of sleep. A low heart rate, low humidity and small deviation from skin temperature of about 33°C [8] are the considered the ideal conditions for restful sleep. In a second IWS study, published in 1986 [9], these parameters were examined for subjects sleeping under wool and polyester-filled duvets of equivalent thermal resistance (insulation) values, at 22°C and 16°C. Body movement during sleep was also examined.

At the lower temperature they found that the subjects' heart rate was significantly lower throughout the sleep period under the wool-filled duvet. An examination of the data suggests that the difference was on average 9 beats per minute, which meant that the heart rate under polyester was, on average, 16% higher than under wool. The humidity in the bed microclimate was higher under polyester most of the time, and examination of the data indicates that it was, on average, higher by 18%. This study also determined that the temperature under the wool-filled duvet was significantly lower (i.e. closer to the optimum 33°C) than under polyester almost all the time. No physiological data for the higher temperature was provided.

They found no difference in limb movement between the two fill types at the lower temperature. At the higher temperature they found that subjects had more incidences of limb movement under wool than under polyester, but that they spent less total time with the body uncovered.

More recently, an AWI-funded study carried out at the University of Sydney [10] concluded that wool bedding 'breathes' more than synthetic (referring to its ability to absorb and desorb moisture, as discussed in Section 3.3. above). The work involved human trials where physiological data (including brain activity and thermal imaging) was collected along with subjective ratings. Tests were carried out at 12°C, 18°C and 24°C. A human analogue (the 'water-filled bladder') was used for more controlled testing.

The tests found that with wool bedding there was an increased duration of the rapid eye movement (REM) sleeping phase compared to synthetics, which the study states is the most beneficial phase of sleep (it is certainly when most dreaming takes place, but its exact purpose is unclear). They also found that subjects reached a comfortable sleeping temperature faster, and remained at that temperature for longer with wool, particularly in the lowest temperature environment.

4.1.2 Studies related to bedding and apparel for infants

There are a few published studies that examined the effect of different textile materials in bedding on the behavior of infants. All seem to have been focused on the use of wool pile fabrics (e.g. sheepskins) as sleeping or nursing pads, and none are recent studies. One of the earliest dates from 1969 [11] and was purely observational, with mothers being given the bed pad to use while keeping a diary detailing the baby's behavior and other observations. Largely the mothers found the bed pads encouraged the babies to sleep longer and they seemed more contented. Concerns were raised over one bed pad from which fiber tufts came loose and might have presented a choking or suffocation risk for the baby; this was related to a faulty sheepskin that had been incorrectly processed.

A subsequent study, the outcomes of which were published in 1970 [12] confirmed the findings of the former, with the use of lambskin 'rugs' resulting in babies reportedly staying warmer, sleeping more soundly and for longer periods. Some mothers also reported that even in hot weather the baby was more comfortable on the wool fleece surface than a cotton sheet.

In a study which collected clinical as well as observational data, Scott and Richards [13] found that low birthweight babies in incubators had greater daily weight gain when on a 22 mm lambswool pile fabric with synthetic backing (as opposed to a natural sheepskin) than when on cotton (fabric structure not given, so assumed to be a flat sheet). This was only a small trial (six babies) but the difference was substantial (31.5 g/day on lambswool compared to 19.6 g/day on cotton) and was attributed to reduced movement and lower heat loss on the lambswool fabric. Powley *et al* [14] reported a small trial of jaundiced babies receiving phototherapy, with similarly beneficial results when lambskins were used (true sheepskins on this occasion). Scott *et al* followed their earlier trial with a larger one (34 babies) in 1983 [15], which confirmed their previous findings, but subsequent research [16,17] using more rigorous measurement techniques suggested that the differences observed may in fact not be statistically significant.

In the wake of the Scott and Richards and Powley *et al* studies, concern was raised over the possible ingestion or inhalation of fibers from artificial sheepskin; for example Tyler *et al* report a baby on what is described as an 'artificial sheepskin' (understood to be synthetic fiber pile) suffering respiratory difficulty due to "a ball of sheepskin fibres" subsequently removed from the mouth and pharynx [18]. In a response to this concern [19], Scott and Richards noted that fiber shedding appeared to be much more of a problem with synthetic fiber pile (fibers were smoother and more slippery than wool), and that synthetic pile fabrics should not be used with newborns. They also advise simple precautions (such as brushing the pile after washing to remove loose fiber, and/or covering the area of pile under the baby's head with a cotton sheet) could be used.

Understandably, thick pile fabrics such as sheepskins appear to be treated with caution as bedding materials for babies, as they might create a surface (or shed fiber) which could obstruct the baby's airways. However, with the advent of the sleep sack, such as the Merino Kids and Halo sleep sacks evaluated in Section 3, it would be possible to incorporate a pile fabric layer to go under the baby without this risk.

It must be noted that in the above-mentioned reports the control against which the wool-based product was compared was not an equivalent pile fabric from an alternative fiber type, but a flat textile. This prevents these studies from indicating the influence of fiber type alone.

Finally, a more recent Israeli study [20] examined the effect of wool or cotton head coverings on a newborn infant's core temperature after a period of time with the mother in the delivery room, before being taken to the nursery. They found that the wool head covering kept the baby significantly warmer than the cotton covering; however the fiber effect in this study was confounded by the two head coverings being of different design. The cotton covering was a loosely applied cotton diaper, while the wool head covering was described as a 'simple hat'. The wool head covering design may simply have been more suitable for its purpose than the cotton head covering.

4.2 Flammability

It is important that all textiles used in bedding and particularly children's sleepwear, resist catching fire and pose a minimal threat should they burn. This is sufficiently important that children's sleepwear sold in many countries (including USA) must conform to a regulatory standard (e.g. 16 CFR 1615/1616; Code of Federal Regulations; Flammability of Children's Sleepwear). This takes into account garment design but also the flammability of the fiber from which the garment is constructed.

A simple measure of the flammability of a material is its 'limiting oxygen index' or LOI. This is defined as the minimum concentration of oxygen in a mixture of oxygen and nitrogen that will just support flaming combustion. The higher the LOI of a material, the less flammable it is, and if the LOI is above 21 then the material is considered 'self-extinguishing'. This is because the proportion of oxygen in air (which is mostly oxygen and nitrogen) is 21%.

The limiting oxygen index for wool is 25.2, while for polyester it is 20.6 [21]. Therefore, wool is less flammable than polyester, and would self-extinguish in the absence of an ignition source. Polyester would not self extinguish as readily. In addition, polyester, like many synthetic fabrics, melts when exposed to high heat. The melted polyester can adhere to the skin causing more severe burn injuries than wool, which decomposes (breaking down to ash) when subjected to high heat. Wool is, therefore, intrinsically safer in sleepwear and bedding textiles than polyester, which may need a chemical treatment to achieve suitable flame retardence.

It should be noted also that fabric construction has a major influence on how readily it will burn. Very lofty low density fabrics (such as fleece fabrics) ignite and burn more rapidly, especially if they have a fuzzy surface.

4.3 Absorption of volatiles

It is now widely known that the chemical properties of wool allow it to absorb volatile compounds from the indoor environment [22]. Wool carpets are able to play a role in controlling indoor air pollution, absorbing nitrogen oxides, sulfur oxides and formaldehyde, all of which can contribute to sick building syndrome [23], and it is likely that wool in other forms (such as bedding and apparel) can play a similar role, albeit on a scale proportional with the amount of wool present. Removing these pollutants from the indoor environment is likely to improve the wellbeing of the building occupants.

As well as absorbing and trapping potentially harmful volatile chemicals, the absorbent nature of wool allows it to trap odor-causing compounds, which can be advantageous in items to be worn next to the skin for a prolonged period.

4.4 Skin irritation or 'prickle'

The uncomfortable itchiness known as 'prickle' that is sometimes attributed to wool clothing and bedding is widely misunderstood. Common misconceptions are that it is due to an allergy to wool, or caused by the scales of the wool fiber. Both of these explanations are incorrect. An allergy to wool is quite rare, and a study has shown the lack of any correlation between a subject's fabric prickle response and their response to wool allergen extracts via a standard scratch test. In other words, people who showed an allergic response to wool found the prickliness of a particular fabric sample no worse than those who did not show an allergic response [24]. Neither are the scales of the wool fiber likely to cause prickle as they are far too small, protruding less than one 1000th of a millimeter from the surface of the fiber. The degradation of the wool fiber scales, routinely carried out as part of the process to make wool machine washable, does not remove prickle from a garment for which it is a problem. In spite of this, the misconception about scales causing prickle is often reported [25].

The actual cause of prickle in wool fabrics (and in fact in fabrics made from any fiber) is the presence of relatively coarse fibers, stiff enough to press into the surface the skin (like pinpricks). Finer fibers do not press into the skin because they buckle when pressed against it. The pain receptors in the skin only respond if sufficient force is applied to them, and for thick fibers this force is reached before the fiber bends over and buckles. For thinner fibers the pain receptor threshold is not reached before the fiber collapses [26,27]. The stiffness and the length of the fibers are important too; a very flexible or long fiber has a greater tendency to collapse when its end presses against the skin.

Prickle is generally only a problem for wool fabrics because of the fact that thick fibers trigger the pain receptors. Cotton is naturally very fine, and synthetics can be manufactured as fine as required, but wool fibers come in various finenesses and even the fleece from a single sheep will have fibers across a range of fineness. This means that only the fiber from sheep that produce fine wools (breeds such as the Merino) are suitable for wearing next to the skin. The superfine merino wool used in the Merino Kids sleep sack will have very few coarse fibers and will be, for almost all people, free of prickle.

It is worth noting that variability between humans plays a role also. Some people are less sensitive to prickle than others; they either have pain receptors that trigger only at higher forces or they are protected by a thicker layer of skin. While it is now accepted that infants perceive pain in the same way as adults [28], we are not aware of any research into how they experience prickle. Finally, it also is worth noting that coarse synthetic fiber would be just as prickly as coarse wool, so it is simply a matter of using the right fiber diameter for the right end-use.

5. Conclusions

In the product comparison reported here, clear differences in thermophysiological comfort-related performance have been identified between the merino wool Merino Kids and polyester Halo sleep sacks. While the Halo sleep sack had substantially higher thermal resistance, this is only of benefit when environmental conditions call for high levels of insulation and remain constant. The Merino Kids sleep sack had much higher moisture vapor absorption, approximately equal moisture vapor transmission and much lower air permeability, all of which indicate a much more sophisticated level of ‘breathability’ of the merino system, with it likely to be better at transferring moisture away from the baby while reducing convective heat loss and mitigating the chilling effect of drafts.

These test results, coupled with the outcomes of previous research into sleeping comfort and the well-known low flammability and volatile absorption properties of wool indicate that merino is an ideal material from which to construct sleep sack bedding systems for infants.

6. References

1. American Academy of Pediatrics Policy Statement, accessed 19th June 2010 at http://aappolicy.aappublications.org/cgi/reprint/pediatrics;116/5/1245.pdf.
2. American SIDS Institute, *Reducing the Ricks of SIDS*, accessed 30th June 2010 at http://www.sids.org/nprevent.htm.
3. Standard: ISO 139:2005 – Textiles – Standard atmospheres for conditioning and testing (2005).

4. Test method: WNZ TM 260 – Thermal resistance of textiles (1995).

5. Test method: BS 5636:1990 – Method for determination of permeability of fabrics to air.

6. *Comparative thermophysiological evaluations of wool and acrylic blankets, wool and polyester filled quilts*. Technical Information Letter 13, International Wool Secretariat, January 1984.

7. K H Umbach, Comparative thermophysiological tests on blankets made from wool and acrylic-fibre-cotton blends. *Journal of the Textile Institute*, 1986, 77(3), 212-222.

8. T H Benzinger, C Kitzinger and M W Pratt, The Human Thermostat. In: *Physiological and behavioral temperature regulation*, J D Hardy, A P Gagge and J A J Stolwijk (eds), Charles C Thomas, USA, 1970.

9. *An ergonomic comparison of wool and polyester-filled quilts*. Technical Information Letter 26, International Wool Secretariat, February 1986.

10. *The Sleeping Comfort Study*, SC01, The Woolmark Company, 2005.

11. N F Roberts and N Sutherland, *Tests of Tanned Lambskins as Bedpads for Young Babies*. Wool Research Organisation of NZ and GL Bowron & Co, Ltd, May 1969.

12. D G Palmer, *Baby-care lambskin rugs: notes on the third experiment*. Wool Research Organisation of NZ, January 1970.

13. S Scott and M Richards, Nursing low-birthweight babies on lambswool. *The Lancet*, 1979, 1(8124), 1028.

14. M Powley, P Nye and P Buckfield, Nursing jaundiced babies on lambskin. *The Lancet*, 1980, 1(8175), 979-980.

15. S Scott, P Lucas, T Cole and M Richards, Weight gain and movement patterns of very low birthweight babies nursed on lambswool. *The Lancet*, 1983, 2(8357), 1014-1016.

16. M F Epstein, Nursing the premature infant: what kind of sheet? *Lancet*, 1984, 1(8369), 174.

17. S B Roberts, J Savage and A Lucas, Does lambswool promote growth in preterm infants? *Lancet*, 1986, 1(8486), 921-922.

18. R M Tyler J Dammers and C van der Linden, Babies eat "sheepskins". *The Lancet*, 1981, 1(8213), 211.

19. S Scott and M Richards, Lambswool is safer for babies. *The Lancet*, 1981, 1(8219), 556.

20. N Lang, R Bromiker and I Arad, The effect of wool vs. cotton head covering and length of stay with the mother following delivery on infant temperature. *International Journal of Nursing Stud*ies, 2004, 41(8), 843-846.

21. L Benisek, Current flammability methods and specification, and the position of wool. *Wool Science Review*, 50, 1974, 40-54.

22. N A G Johnson, E J Wood, P E Ingham, S J McNeil and I D McFarlane, Wool as a Technical Fibre. *Journal of the Textile Institute*, 2003, 94(3) 26-41.

23. S M Causer, R C McMillan and W G Bryson, The role of wool carpets in controlling indoor air pollution. In: *Proceedings of the 9th International Wool Textile Research Conference*, Biella (Italy), 28th June to 5th July 1995.

24. R K Garnsworthy, R L Gully, R P Kandiah, P Kenins, RJ Mayfield and RA Westerman, *Understanding the Causes of Prickle and Itch from the Skin Contact of Fabrics*. CSIRO Division of Wool Technology Report No. G64, 1988.

25. P. Hadfield, Wool comes up to scratch. *New Scientist*, 25 October 1997, pg 7.

26. G R S Naylor, C J Veitch and R J Mayfield, Fabric-Evoked Prickle. *Textile Research Journal*, 1992, 62(8), 487-493.

27. R K Garnsworthy, R L Gully, P Kenins, R J Mayfield and R A Westerman. Identification of the Physical Stimulus and the Neural Basis of Fabric-Evoked Prickle. *Journal of Neurophysiolog*y, 1988, 59(4), 1083-1096.

28. P J Mathew and J L Mathew, Assessment and management of pain in infants. *Postgraduate Medical Journal*, 2003, 79, 438-443.

7. Appendix A
Complete testing results

Thickness and weight

Product	Thickness measurement (mm)					Average (mm)	SD
	1	2	3	4	5		
Merino Kids	2.10	2.05	2.12	2.18	2.15	**2.12**	0.05
Halo	3.68	3.70	3.65	3.60	3.60	**3.65**	0.05

Product	15cm × 15cm Sample Weight (g)					Weight (g/m²)
	1	2	3	Average	SD	
Merino Kids	9.174	9.163	8.994	9.110	0.10	**405**
Halo	4.798	4.919	4.877	4.865	0.06	**216**

Thermal resistance

Product	Specimen	Resistance m²K/W	Conductivity W/(m·K)	TOG result
Merino Kids	1	0.0311	0.0681	0.311
	2	0.0324	0.0655	0.324
	Average	**0.0318**	**0.0668**	**0.318**
	SD	0.0009	0.0018	0.009
Halo	1	0.0911	0.0401	0.911
	2	0.0860	0.0424	0.860
	Average	**0.0885**	**0.0413**	**0.885**
	SD	0.0036	0.0017	0.036

Moisture vapor absorption and transmission

Product	Fabric weight (g/m²)	Moisture Vapor Absorption g/m²				
		1	2	3	Average	SD
Merino Kids	405	28.68	28.59	29.18	**28.82**	0.32
Halo	216	0.41	0.36	0.25	**0.34**	0.08

Product	Fabric	Moisture Vapor Transmission

	weight (g/m²)	g/m²				
		1	2	3	Average	SD
Merino Kids	405	406.1	404.7	405.4	**405.4**	0.70
Halo	216	410.4	418.3	412.6	**413.8**	4.08

Air permeability

Product	Measured over (inch)	Front	Back	Mean values			Airflow / 1 inch	Air Permeability (ft^3/min/in water/ft^2)
				Face	Back	Combined		
Merino Kids	1	19.5	20.0	20.8	20.0	20.4	20.4	**167**
		20.5	19.6					
		21.5	20.5					
		22.0	19.8					
		20.4	20.1					
SD				0.98	0.34	0.81		
Halo	0.5	25.0	22.5	24.7	23.2	24.0	47.9	**393**
		25.0	23.2					
		24.5	24.0					
		24.0	22.5					
		24.8	24.0					
SD				0.42	0.75	0.94		