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A comparative study of three different hand drying methods: paper towel, warm air dryer, Dyson® Airblade dryer.

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Part A: The drying efficiency of different hand drying methods.

Part B: Changes in the number of different types of bacteria on the hands before and after drying using paper towel, warm air dryer and Dyson® Airblade dryer (and other observations).

Part C: Potential contamination of other users and the washroom environment caused by paper towel, warm air dryer and Dyson® Airblade dryer.

Part D: Bacterial sampling of Dyson® Airblade dryers in public washrooms.

Introduction

Following Semmelweis's observations on the effect of hand washing on the incidence of puerperal fever in a maternity ward in the 19th Century, good hand hygiene has been recognized as an important factor in controlling the spread of infectious disease and, more recently, antibiotic-resistant bacteria in hospitals and in the community. Meticillin-resistant ***Staphylococcus aureus*** (MRSA), ***Clostridium difficile***, ***Enterococcus faecalis*** and other agents causing hospital-acquired infections can be transmitted to patients by the hands of medical staff. Similarly, food-poisoning organisms can be transmitted to food by dirty hands and subsequently cause illness to those eating it.

There have been many studies on the benefits of hand washing and on the efficacy of different hand washing agents but relatively few on the contribution of hand drying to hand hygiene. However, there is increasing awareness of its importance in the overall hand hygiene debate.

Disregarding the types of textile towel where users dry their hands on the same area of material as previous users and which have been condemned on hygiene grounds for many years, the three main hand drying methods available in public washrooms have until fairly recently been: paper towels, continuous roller towels (where a fresh area of towel is available for each user) and warm air dryers. However, in 2006 Dyson introduced a new type of electric hand dryer, the Airblade, where users insert their hands into a slot whilst unheated air is forced out through slits at high speed and removes water from the hands by scraping. Other manufacturers such as Veltia have also introduced electric hand dryers which remove water using currents of unheated air but these were not tested in this study, only the Dyson Airblade.

Blackmore (1989) showed that in normal use warm air dryers increase the number of bacteria that can be isolated from the fingerpads after drying. She also recorded decreases in the bacterial numbers on fingerpads when paper towels and continuous roller towels were used for hand drying. Two previous studies carried out by the University of Westminster (Knights ***et al***., 1993; Redway ***et al***., 1994) showed similar results in that on average warm air dryers substantially increase the number of bacteria on the hands of users. Compared to the number present on subjects' hands before washing and drying, the first study found the mean percentage increase in the number of bacteria on the fingerpads after using a warm air dryer was 504%. The second study found mean percentage increases in different types of bacteria on the fingerpads of subjects after using a warm air dryer ranging from 169% to 438%. Conversely, both studies showed that paper towels and continuous roller towels decrease the mean number of all types of bacteria on the fingerpads of users.

Since these studies all other investigations by the University of Westminster have consistently shown that towels, both continuous roller towels and paper, perform significantly better than warm air dryers in terms of speed, drying efficiency, hand hygiene and bacterial contamination. However, until this present study, the performance of the Dyson Airblade dryer had not been investigated by the University nor compared to other hand drying methods.

The main aims of this study were to:

- Measure the drying efficiency of paper towel, warm air dryer and Dyson Airblade dryer.
- Calculate any changes in the numbers of different types of bacteria on the fingerpads and palms of 20 subjects (10 male, 10 female) before and after washing and drying their hands using three different hand drying methods: paper towel, warm air dryer, Dyson Airblade dryer.
- Assess any potential contamination of users and the washroom environment caused by the use of paper towel, warm air dryer and Dyson Airblade dryer.
- Sample any bacterial contamination of Dyson Airblade dryers in public washrooms.
- Make any other observations, measurements and recordings of relevance to the comparison of the three different hand drying methods used in this study.

Part A: The drying efficiency of different hand drying methods.

Introduction

It is generally accepted that the transmission of bacteria and other microorganisms is more likely to occur from wet skin than from dry skin (Gould 1994). This happens partly because of the ease of water transfer from one surface to another and partly because microorganisms prefer a damp environment and, therefore, may be in a better physiological state to colonize touched surfaces. The amount of residual water left on the hands of users after drying is directly related to the number of bacteria that are transferred by contact - the greater the amount, the more bacteria (Patrick ***et al***., 1997). Knights ***et al***. (1993) showed that warm air dryers in normal use do not dry the hands as efficiently as either paper or continuous roller towels. Warm air dryers in normal use achieved only 55% dryness of the hands of men and 68% of the hands of women. In contrast, both types of towel in normal use achieved 93% or more dryness of the hands of both sexes. It is highly likely that the significantly poorer hygiene performance of warm air dryers shown in this and other studies was partly due to the low drying efficiency of dryers and the consequent greater amount of water remaining on the fingerpads and palms of the hand after their use.

In this present study a similar method to that used by Knights ***et al***. (1993) was employed to compare the drying efficiency of 5 different types of paper towel with a warm air dryer and a Dyson Airblade dryer.

Methods and materials

Hand drying methods used:

i) Paper towel 1 (PT 1) 2-ply 100% recycled fibre.
ii) Paper towel 2 (PT 2) 2-ply.
iii) Paper towel 3 (PT 3) 2-ply through-air dried (TAD).
iv) Paper towel 4 (PT 4) 1-ply.
v) Paper towel 5 (PT 5) 1-ply.
vi) Warm air dryer (WAD): World Dryer Corporation, "***Electric-Aire***", model LE48.
vii) Dyson® Airblade dryer (DAB): model AB01.

1. Sets of 5 paper towels (PT 1) were placed in sterile plastic bags and weighed prior to use.

2. Two volunteers were asked to dip their hands up to the wrists in warm water (temperature = 40^{o}C) for 10 seconds, shake them thrice, and then dry them for 10 seconds using one of the 7 hand drying methods.

3. All the water remaining on the surface of the hands was then carefully removed by the investigator with one of the sets of 5 pre-weighed paper towels using a standardized protocol for 40 seconds.

4. The damp towels were returned to their plastic bag, re-weighed and the amount of water removed from the hands calculated.

5. The operation was repeated using increasing drying times at 10-second intervals: 20, 30, 40, 50 and 60 seconds.

6. To estimate the total amount of water on undried hands immediately after wetting and with no drying (time = 0 seconds), wet hands were dried thoroughly on 5 pre-weighed paper towel and the weight gain recorded. It was then possible to calculate the percentage dryness of the hands as the mean percentage of the total water load removed after the use of each drying method at each time as follows:

   Percentage (%) dryness =

   $$\frac{\text{weight of water on undried hands - weight of water on dried hands}}{\text{weight of water on undried hands}} \times 100$$

7. The order of drying times and the drying methods were randomised to minimize any possible effect of external factors such as variations in room temperature, relative humidity or human behaviour.

Results

Table 1

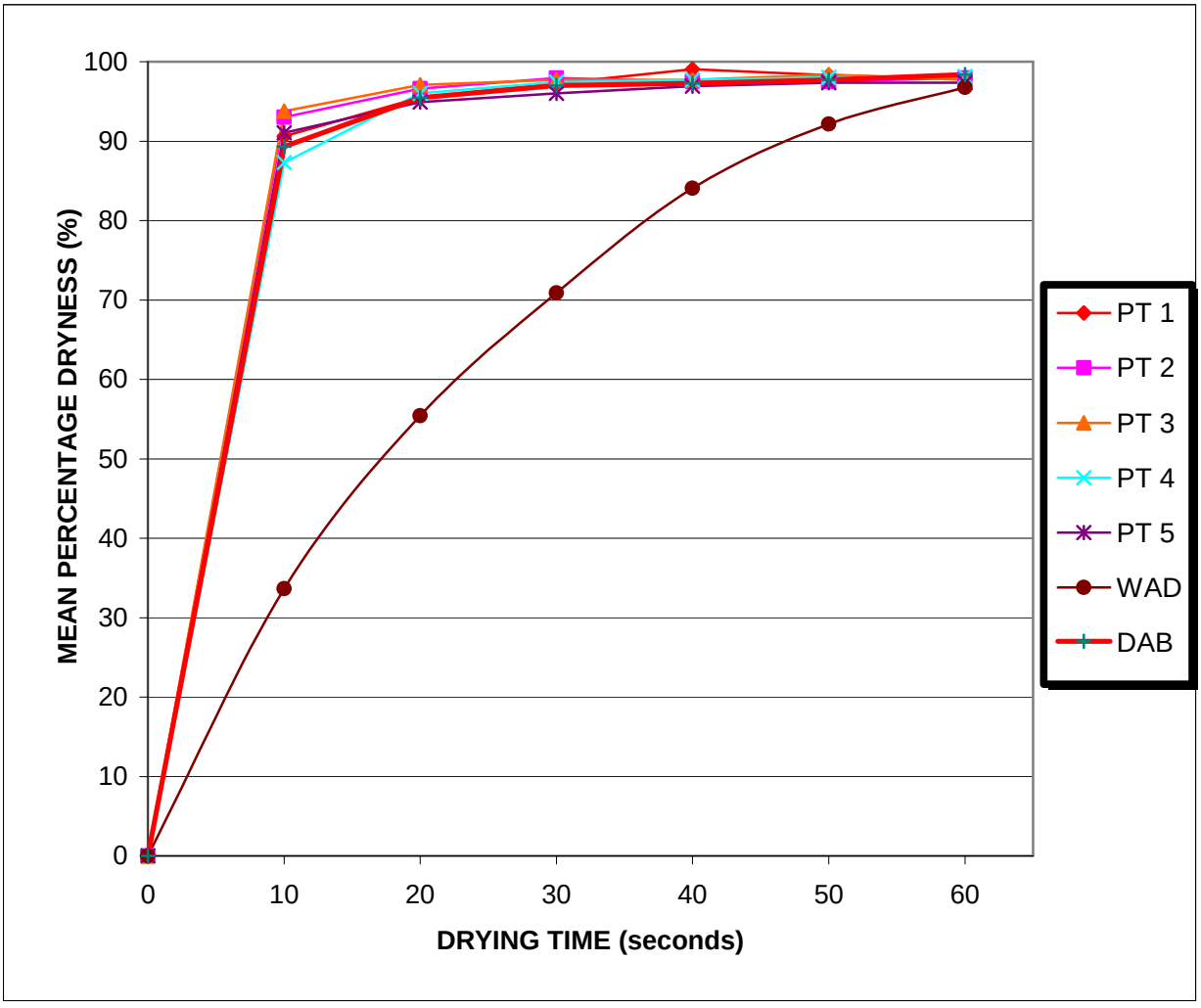
Showing the mean percentage dryness (%) of the hands of subjects after using five different types of paper towel (PT), a warm air dryer (WAD), and a Dyson Airblade dryer (DAB) for different drying times.

DRYING TIME (seconds)	HAND DRYING METHOD						
	PT 1	PT 2	PT 3	PT 4	PT 5	WAD	DAB
0	00.0	00.0	00.0	00.0	00.0	00.0	00.0
10	90.6	93.0	93.0	87.3	91.0	33.7	89.3
20	95.5	96.6	96.6	96.0	94.9	55.4	95.5
30	97.3	97.9	97.9	97.4	96.0	70.9	97.0
40	99.0	97.5	97.5	97.7	96.9	84.1	97.3
50	98.3	97.5	97.5	98.0	97.4	92.1	97.7
60	97.9	97.9	97.9	98.2	97.4	96.8	98.4

(N = 2)

Figure 1

Graph of the mean percentage dryness of the hands of subjects against drying time using five different types of paper towel (PT), a warm air dryer (WAD), and a Dyson Airblade dryer DAB).



(N = 2)

Table 2
Showing the mean times to achieve a minimum of 90% dryness of the hands using five different types of paper towel (PT), a warm air dryer (WAD), and a Dyson Airblade dryer (DAB).

HAND DRYING METHOD	MEAN TIME TO ACHIEVE A MINIMUM OF 90% DRYNESS (seconds)
PT 1	10
PT 2	10
PT 3	10
PT 4	11
PT 5	10
WAD	47
DAB	10

(N = 2)

Conclusions and discussion

The results shown in ***Tables 1*** and ***2*** show that the 5 types of paper towel and the Dyson Airblade dryer were equally efficient at drying the hands of users, all of them achieving 90% dryness in approximately 10 seconds. Any slight differences between these 6 hand drying methods were not considered significant. However, the results show that the warm air dryer was considerably less efficient (***i.e***. slower) than the 5 types of paper towel and also the Dyson Airblade dryer and took over 4 times as long to achieve 90% dryness of the hands. The results in ***Table 1*** are represented graphically in ***Figure 1***.

Knights ***et al***. (1993) also showed warm air dryers were much less efficient than towels (paper or textile) at drying the hands. Their results were similar to those of this study with the difference that the Dyson Airblade was unavailable and not tested at that time.

Therefore, the instructions on a Dyson Airblade dryer to use it for 10 seconds seem appropriate. Similarly, their claim that it is "***the fastest hand dryer***" seem to be borne out by the results of this part of the study which suggest that it represents a considerable improvement over warm air dryers in terms of drying efficiency, ***i.e***. speed of drying.

However, although damp hands encourage the transmission and survival of bacteria on the hands (Gould, 1994; Patrick ***et al***., 1997), there are other factors which can affect the hygiene performance of a hand drying method. These factors include: the degree of frictional removal of dirt, grease, bacteria and skin squames from the hands; the absorbance and softness of material used to dry the hands; the emission of bacteria in the air flows of electric hand dryers; the contamination of the surfaces of hand drying devices. The real test of hygiene performance is not the percentage dryness of the hands alone but the number of bacteria removed from, or remaining on, the hands of users after use. This, and other indicators of hygiene performance, including Dyson's claim that the Airblade is "***the most hygienic hand dryer***", were investigated in other parts of this study.

Part B: Changes in the number of different types of bacteria on the hands before and after drying using paper towel, warm air dryer and Dyson® Airblade dryer (and other observations).

Introduction

Previous studies (Blackmore,1989; Knights ***et al***., 1993; Redway ***et al***., 1994) have used the 'contact plate' method to assess changes in the number of bacteria present on the hands before and after washing and drying. The method involves pressing the fingerpads onto nutritive agar plates, growing any transferred bacteria at 37^{o}C overnight and then counting the number of colony-forming units (cfu's) present. This method has been shown to be relatively quick and sufficiently accurate for this type of study (Sanderson & Weissler, 1992). In addition to contact plates, this present study also used swab sampling of an area of the palm of the hand before and after the use of paper towel, warm air dryer or Dyson Airblade dryer.

The hand drying times used in this part of the study for the paper towels (10 seconds) and the warm air dryer (20 seconds) were based on observations (Redway ***et al***., 1997) in public washrooms of the average times used by members of the public. However, because it is relatively new, no such observations were available for the Dyson Airblade dryer and the manufacturer's recommended time of 10 seconds was used.

Methods and materials

1. 20 subjects (10 male and 10 female) were recruited covering an age range 18 to 60 years.

2. Subjects were asked to visit a public washroom in a normal fashion and return to the laboratory without washing their hands. No instructions were given by the investigator as to how they should use the washroom or what they should do in it.

3. Three different agar growth media were used to sample the dominant hand of subjects before washing and drying (BD) and after washing and drying (AD). The media used and in this order were:

   Nutrient Agar [NA] (Oxoid)

   NA is a non-selective, general purpose growth medium which would be expected to grow most non-fastidious types of bacteria, including skin and gut bacteria.

   Cystine-Lactose-Electrolyte-Deficient Medium [CLED] (Oxoid)

   CLED medium supports the growth of potential pathogens from the gut giving good colonial differentiation and clear diagnostic characteristics for ***Escherichia coli***, ***Salmonella*** species, ***Enterococcus*** species, ***etc***.
   Escherichia coli produces large yellow colonies due to fermentation of the

lactose, ***Salmonella*** species produces flat blue colonies and ***Enterococcus*** species produce small yellow colonies. Other types of bacteria produce different colonial morphologies.

Mannitol-Salt Agar [MSA] (Oxoid)

MSA is a selective growth medium used for the isolation of staphylococci; most other bacteria are inhibited by the high salt content. Presumptive pathogenic, coagulase-positive ***Staphylococcus aureus*** colonies are surrounded by yellow zones (due to acid production from the fermentation of mannitol) whilst non-coagulase-positive staphylococci produce colonies with reddish purple zones.

4. Areas of hand sampled were: fingerpads (by direct contact with the agar plate surface) and the palm (by swabbing and inoculation of agar plates).

   a) For sampling fingerpads, subjects were asked to firmly press the fingerpads of their ring, middle and index fingers onto the surface of 3 agar plates in turn (NA, CLED, MSA). A sterile swab moistened with ¼ strength Ringers solution was then used to swab the entire surface of each agar plate so as to spread and disperse any potential colonies and enable them to be counted more easily.

   b) For sampling palms, a sterile metal former with a circular hole in it (diameter 4.2 cm) was placed on the palm of subjects and a sterile swab moistened with sterile ¼ strength Ringers solution was then used to swab half the area. The cotton bud of the swab was then aseptically removed to 3 ml of ¼ strength Ringers solution and vortexed for 10 seconds. 0.1 ml of this suspension was then dispensed onto the surface of 3 agar plates (NA, CLED, MSA) and spread using a sterile glass spreader.

5. Subjects were then asked to wash and rinse their hands for a total of 10 seconds using one squirt (0.83 ml) of a commonly available liquid soap (Johnson Diversy "***Soft Care***" hand washing cream) from a dispenser which was operated by the researcher and running tap water. Subjects were then requested to dry them using one of the following 4 hand drying methods and for the times indicated:

   i) Paper towel 1 (PT 1): 2-ply 100% recycled fibre. 10 seconds

   ii) Paper towel 3 (PT 3): 2-ply through-air dried (TAD). 10 seconds.

   iii) Warm air dryer (WAD). World Dryer Corporation, "***Electric-Aire***", Model LE48. 20 seconds.

   iv) Dyson® Airblade dryer (DAB). Model AB01. 10 seconds

   Subjects were not given any instructions as to how to dry their hands and were allowed to take as many paper towels as they wished but only within 10

seconds. Similarly, subjects were not instructed as to how to use the WAD or DAB dryer but were stopped after 20 and 10 seconds respectively.

6. The sampling technique as in Stage 4 was repeated after washing and drying (AD), ***viz***. fingerpad and palm inoculation of the three different agar growth media in turn. For palm sampling, the half of the circular area not swabbed previously for the BD sample was used.

7. All agar plates were incubated at 37^{o}C and examined after 1 and 2 days for bacterial growth. The number of colonies on each plate was recorded and, where appropriate, differentiation made between different types of colony that aid identification of the bacterial type, ***e.g***. yellow zones around colonies on MSA suggesting ***Staphylococcus aureus***, large yellow colonies on CLED Medium suggesting ***Escherichia coli***. Counts on plates which showed too many colonies to count were scored as 200, which is considered the upper limit for accurate counting.

8. All 20 subjects were re-tested exactly as in Stages 2 - 6 above but on a different days when they were required to a different hand drying method each day.

9. The order that subjects were required to use the four different hand drying methods was randomised between subjects to minimize any external effects such as variation in temperature or humidity on different days.

10. Results were recorded, tabulated and statistically analysed. The percentage (%) changes in bacterial numbers (as colony-forming units) on the hands were calculated as follows:

$$\frac{\text{number after drying} - \text{number before drying}}{\text{number before drying}} \times 100$$

The paired t-test was used to establish if there were any significant differences between the mean number of different types of bacteria on the hands of subjects before washing and drying their hands (BD) and after washing and drying their hands (AD) using the four different hand drying methods. The analysis was applied to all bacterial types that grow on nutrient agar, plus potential skin pathogens on MSA and gut bacteria on CLED. The 4 different drying methods were also statistically compared by t-tests on the AD counts of subjects after using them.

11. Controls: Plates of all 3 agar growth media were used at regular intervals to test samples of the paper towels, the air flow of the warm air dryer, the air flow of the Dyson Airblade dryer, the liquid soap and the tap water for the presence of bacteria. For the paper towels bacterial contamination was tested by using the end of a sterile glass beaker to press a set area (15.90 cm^2) of towel onto an agar plate. Similarly, the liquid soap and the tap water were tested for the presence of bacteria by plating out 0.1 ml aliquots onto agar plates and spreading with a sterile glass spreader. The warm air dryer's airflow was tested by holding agar plates beneath it at a distance of 10 cm

for 20 seconds. The Dyson Airblade dryer's airflow was tested by holding agar plates in the air flow emitted from the sides of the device for 10 seconds. Control plates were incubated at 37^{o}C and examined after 1 and 2 days for the presence of bacterial colonies.

12. Measurements were taken using an environmental meter (CEM DT-8820) at regular intervals of the laboratory ambient temperature, tap water temperature, air flow temperature from the two dryers, the relative humidity in the laboratory and the noise levels when the dryers were running. The power consumption of the 2 electric dryers was also recorded. Some of the same measurements were also made in the public washrooms used in Part D of this study.

Results

Table 1
Mean counts and percentage changes in bacterial numbers (CFUs) on fingerpads before and after washing and drying hands using different hand drying methods.

HAND DRYING METHOD	GROWTH MEDIUM	COLONY TYPE	MEAN BEFORE DRY COUNT (BD)	MEAN AFTER DRY COUNT (AD)	MEAN CHANGE (%)	T-TEST (p)
PT 1	NA	ALL	1478	819	-44.6	0.0980
PT 3	NA	ALL	1296	229	-76.9	0.0020
WAD	NA	ALL	763	2185	+186.4	0.0002
DAB	NA	ALL	1264	1932	+52.8	0.0310
PT 1	CLED	ALL	1068	498	-53.4	0.1700
PT 3	CLED	ALL	779	230	-70.5	0.0170
WAD	CLED	ALL	808	2459	+204.3	0.0002
DAB	CLED	ALL	1291	1653	+28.0	0.2890
PT 1	MSA	MAN +	508	211	-58.5	0.2760
PT 3	MSA	MAN +	519	44	-91.5	0.0700
WAD	MSA	MAN +	228	1172	+414.0	0.0100
DAB	MSA	MAN +	297	871	+193.3	0.0120
PT 1	MSA	MAN -	854	371	-56.6	0.0360
PT 3	MSA	MAN -	808	256	-68.3	0.0370
WAD	MSA	MAN -	661	1415	+114.1	0.0200
DAB	MSA	MAN -	807	739	-8.4	0.8200
PT 1	MSA	ALL	1362	582	-57.3	0.0320
PT 3	MSA	ALL	1327	300	-77.4	0.0240
WAD	MSA	ALL	889	2587	+191.0	0.0001
DAB	MSA	ALL	1104	1610	+45.8	0.0700
PT 1	TOTAL	ALL	3908	1899	-51.4	0.0660
PT 3	TOTAL	ALL	3402	829	-75.6	0.0050
WAD	TOTAL	ALL	2460	7231	+193.9	0.0001
DAB	TOTAL	ALL	3659	5195	+42.0	0.0650

(N = 20)

Key to *Tables 1 – 4* and *Figures 1 - 4*:
PT = paper towel (1 or 3); WAD = warm air dryer; DAB = Dyson Airblade dryer.
CFU = colony-forming unit; NA = nutrient agar; CLED = cystine-lactose-electrolyte-deficient medium; MSA = mannitol salt agar; MAN + = acid from mannitol positive; MAN - = acid from mannitol negative; ALL = total number of CFUs (all types of colony); TOTAL = total number of colonies on all three media (NA, CLED, MSA).
↓ = decrease in bacterial count after washing and drying;
↑ = increase in bacterial count after washing and drying.
Change statistically significant at the limit of probability as follows:
* $p < 0.1$ (low significance); ** $p < 0.05$ (significant);
*** $p < 0.01$ (highly significant); **** $p < 0.001$ (extremely significant).

The result shown in ***Table 1*** are summarized in ***Table 2*** and represented graphically in ***Figures 1 – 4***.

Table 2
Summary of mean percentage changes in bacterial numbers on fingerpads before and after washing and drying hands using different hand drying methods.

GROWTH MEDIUM	COLONY TYPE	PAPER TOWEL 1 (PT 1)	PAPER TOWEL 3 (PT 3)	WARM AIR DRYER (WAD)	DYSON AIRBLADE DRYER (DAB)
NA	ALL	-44.6 ↓ *	-76.9 ↓ ***	+186.4 ↑ ***	+52.8 ↑ **
CLED	ALL	-53.4 ↓	-70.5 ↓ **	+204.3 ↑ ****	+28.0 ↑
MSA	MAN +	-58.5 ↓	-91.5 ↓ *	+414.0 ↑ ***	+193.3 ↑ **
MSA	MAN -	-56.6 ↓ **	-68.3 ↓ **	+114.1 ↑ **	-8.4 ↓
MSA	ALL	-57.3 ↓ **	-77.4 ↓ **	+191.0 ↑ ****	+45.8 ↑ *
TOTAL	ALL	-51.4 ↓ *	-75.6 ↓ ***	+193.9 ↑ ****	+42.0 ↑ *

Table 3
Mean counts and percentage changes in bacterial numbers (CFUs) on palms before and after washing and drying hands using different hand drying methods.

GROWTH MEDIUM	COLONY TYPE	HAND DRYING METHOD	MEAN BEFORE DRY COUNT (BD)	MEAN AFTER DRY COUNT (AD)	MEAN CHANGE (%)	T-TEST (p)
NA	ALL	PT 1	599	231	-61.4	0.046
NA	ALL	PT 3	485	107	-77.9	0.063
NA	ALL	WAD	365	1206	+230.4	0.005
NA	ALL	DAB	716	781	+9.1	0.773
CLED	ALL	PT 1	354	210	-40.7	0.352
CLED	ALL	PT 3	401	114	-71.6	0.132
CLED	ALL	WAD	360	1234	+242.8	0.021
CLED	ALL	DAB	583	663	+13.7	0.698
MSA	MAN +	PT 1	62	32	-48.4	0.193
MSA	MAN +	PT 3	75	29	-61.3	0.065
MSA	MAN +	WAD	66	382	+478.8	0.126
MSA	MAN +	DAB	379	336	-11.3	0.830
MSA	MAN -	PT 1	323	217	-32.8	0.146
MSA	MAN -	PT 3	325	48	-85.2	0.170
MSA	MAN -	WAD	202	698	+245.5	0.027
MSA	MAN -	DAB	219	399	+82.2	0.052
MSA	ALL	PT 1	385	249	-35.3	0.125
MSA	ALL	PT 3	400	77	-80.8	0.110
MSA	ALL	WAD	268	1080	+303.0	0.006
MSA	ALL	DAB	598	735	+22.9	0.545
TOTAL	ALL	PT 1	1388	690	-48.4	0.083
TOTAL	ALL	PT 3	1286	298	-76.8	0.093
TOTAL	ALL	WAD	993	3520	+254.5	0.004
TOTAL	ALL	DAB	1897	2179	+14.9	0.664

(N = 20)

The result shown in ***Table 3*** are summarized in ***Table 4*** and represented graphically in ***Figures 1 – 4***.

Table 4
Summary of mean percentage changes in bacterial numbers on palms before and after washing and drying hands using different hand drying methods.

GROWTH MEDIUM	COLONY TYPE	PAPER TOWEL 1 (PT 1)	PAPER TOWEL 3 (PT 3)	WARM AIR DRYER (WAD)	DYSON AIRBLADE DRYER (DAB)
NA	ALL	-61.4 ↓ **	-77.9 ↓ *	+230.4 ↑ ***	+9.1 ↑
CLED	ALL	-40.7 ↓	-71.6 ↓	+242.8 ↑ **	+13.7 ↑
MSA	MAN +	-48.4 ↓	-61.3 ↓ *	+478.8 ↑	-11.3 ↓
MSA	MAN -	-32.8 ↓	-85.2 ↓	+245.5 ↑ **	+82.2 ↑ *
MSA	ALL	-35.3 ↓	-80.8 ↓	+303.0 ↑ ***	+22.9 ↑
TOTAL	ALL	-48.4 ↓ *	-76.8 ↓ *	+254.5 ↑ ***	+14.9 ↑

Table 5
T-test results (p values) comparing the bacterial counts on subjects' hands after using different hand drying methods.

DRYING METHOD	FINGERPADS			PALMS		
	PT 1	PT 3	WAD	PT 1	PT 3	WAD
PT 3	0.073 *	NA	NA	0.090 *	NA	NA
WAD	0.00003 ****	0.000001 ****	NA	0.005 ***	0.003 ***	NA
DAB	0.0005 ****	0.00001 ****	0.037 **	0.012 **	0.006 ***	0.185

Key to *Table 5*:
PT = paper towel (1 or 3); WAD = warm air dryer; DAB = Dyson Airblade dryer.
NA = not applicable (redundant comparison).

* $p < 0.1$ (low significance); ** $p < 0.05$ (significant);
*** $p < 0.01$ (highly significant); **** $p < 0.001$ (extremely significant).

Figure 1

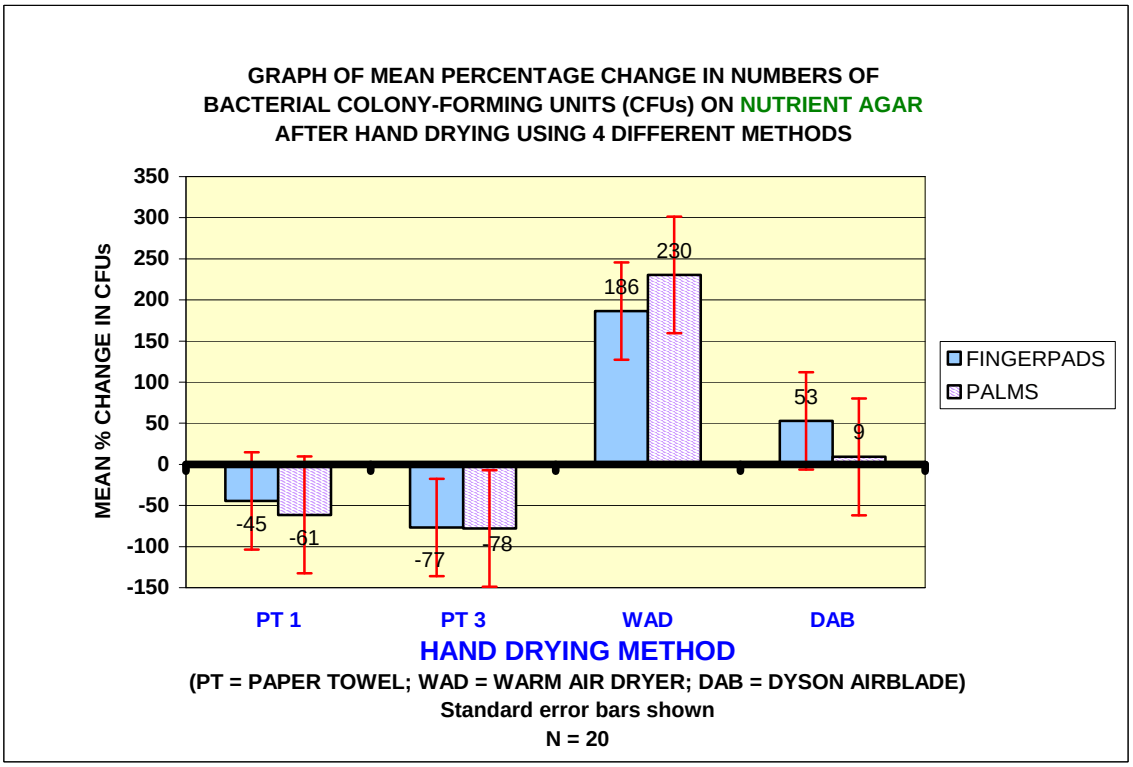


Figure 2

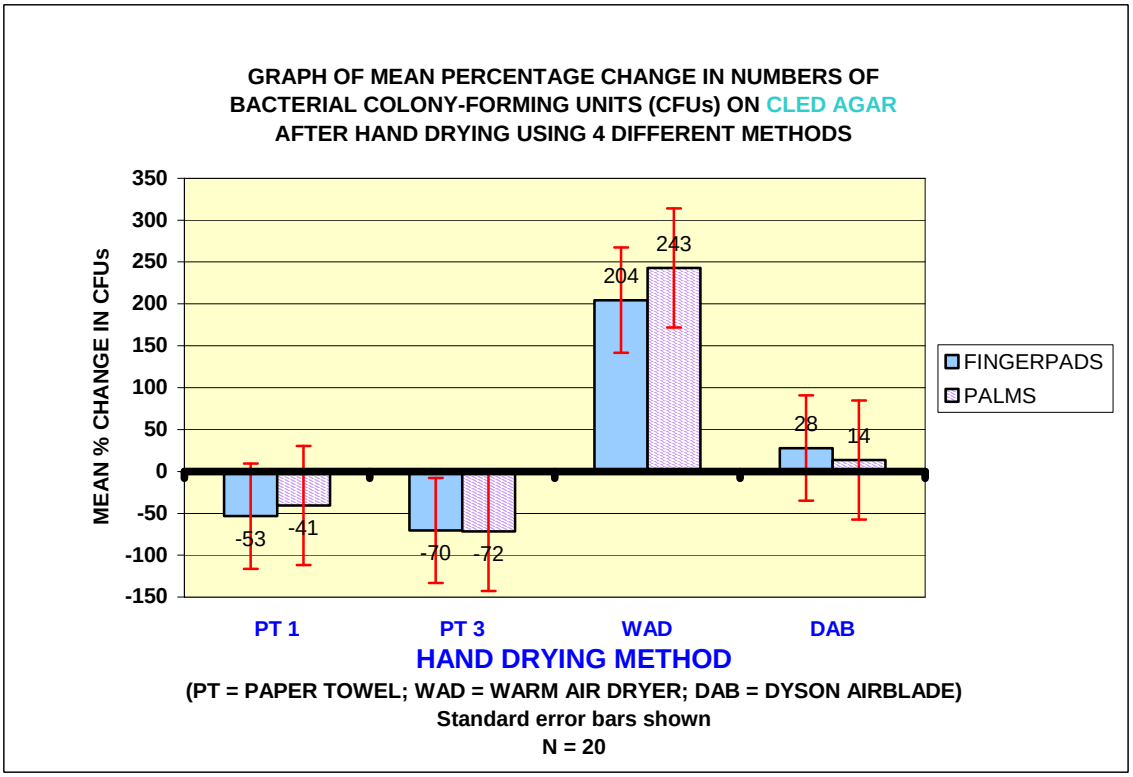


Figure 3

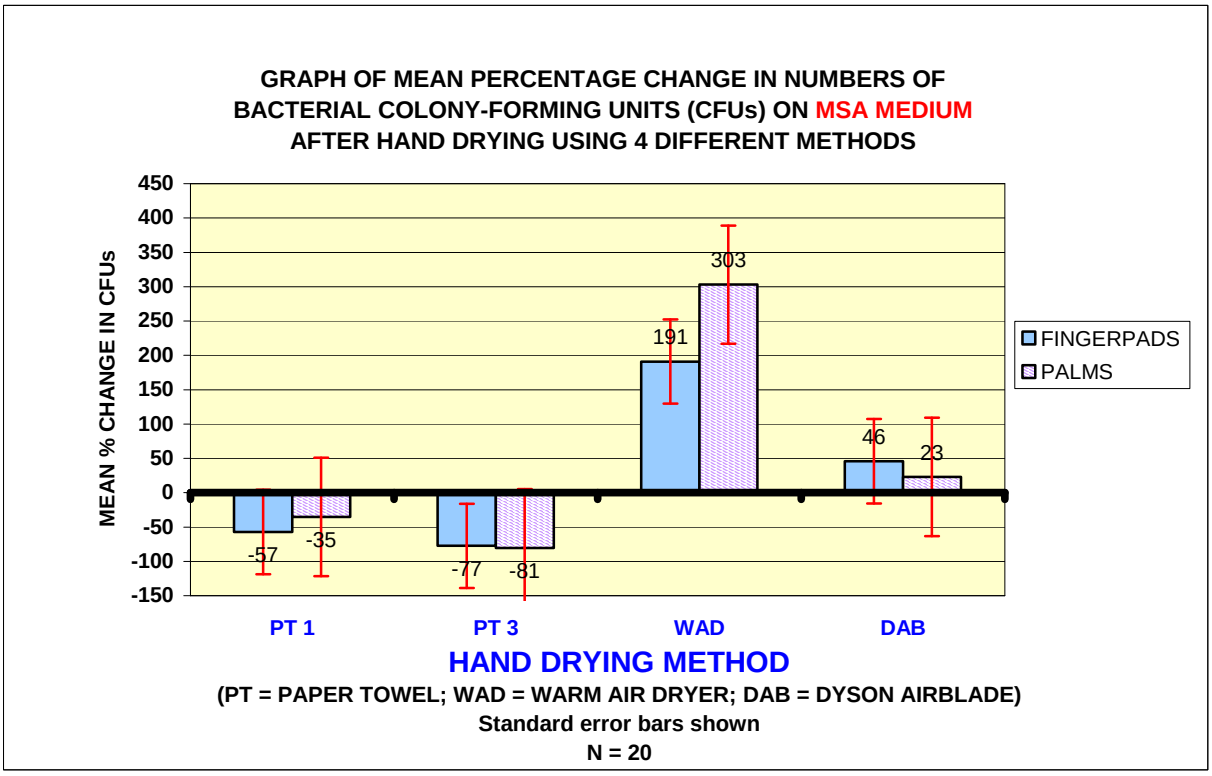
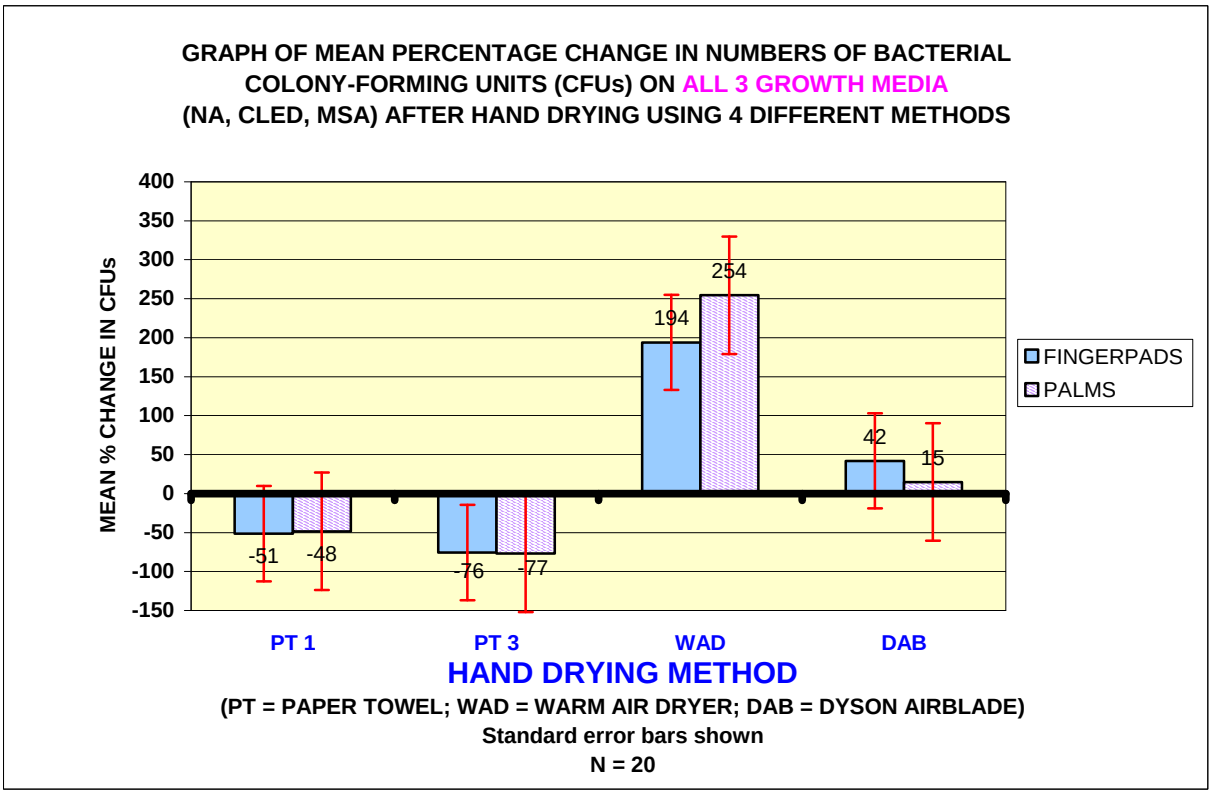


Figure 4



Control results

Table 6
Means of bacterial colony counts for controls on different growth media after incubation at 37°C for 2 days.

CONTROL ITEM	NA	CLED	MSA
PT 1 (per cm^2)	0.13	0.06	0.06
PT 3 (per cm^2)	0.00	0.00	0.00
WAD (20 sec.)	1.40	0.00	0.40
DAB (10 sec.)	1.00	0.00	0.20
Sterile Ringer's solution (per ml)	0.00	0.00	0.00
Tap water (per ml)	30.00	30.00	40.00
Liquid soap (per ml)	0.00	0.00	0.00

(N = 5)

Key to *Table 6*:
PT = paper towel (1 or 3); WAD = warm air dryer; DAB = Dyson Airblade dryer; NA = nutrient agar; CLED = cystine-lactose-electrolyte-deficient medium; MSA = mannitol salt agar.

Measurements

Table 7
Measurements in the laboratory and a public washroom.

MEASUREMENT	MINIMUM	MAXIMUM	MEAN (N = 10)
Laboratory ambient temperature (°C)	22.9	26.7	24.3
Washroom ambient temperature (°C)	21.8	26.9	23.2
Laboratory tap water temperature (°C)	21.3	24.9	22.7
WAD air flow temperature (°C) [20-second run]	50.5	59.1	55.6
DAB air flow temperature (°C) [10-second run]	36.6	40.7	39.2
Laboratory relative humidity (%)	33.6	51.6	47.0
Washroom relative humidity (%)	36.6	49.2	44.6
Background laboratory noise level (dB)	51.2	52.7	51.8
Noise level (dB) with laboratory DAB on at 0.5 m distance	94.7	93.7	94.1
Noise level (dB) with laboratory DAB on at 1.0 m distance	85.1	89.3	87.4
Noise level (dB) with laboratory DAB on at 2.0 m distance	85.4	87.6	86.3
Background washroom noise level (dB)	55.5	58.7	57.8
Noise level (dB) with one washroom DAB on at 2.0 m distance	ND	ND	83.6
Noise level (dB) with one washroom DAB on at 10.0 m distance	ND	ND	77.9
Noise level (dB) with two washroom DABs on at 2.0 m distance	ND	ND	92.0
Power consumption of WAD (W)	ND	1400-1600	N/A
Power consumption of DAB (W)	1 (standby)	1600	N/A

Key to *Table 7*:
WAD = warm air dryer; DAB = Dyson Airblade dryer; dB = decibel: ND no data; W = watts; N/A = not applicable.

Conclusions and discussion

The experimental protocol used in this study attempted to reproduce the public's usual hand washing and drying practices as closely as possible. The times used for washing and drying the hands were based on those shown by a previous study (Knights ***et al***., 1993) to be the averages for men and women using paper towels (10 seconds) and warm air dryers (20 seconds) in real public washrooms, ***i.e***. under 'normal', non-laboratory conditions. The average time that men use warm air dryers was found to be 20 seconds whilst for women it was 25 seconds. By comparison, Patrick ***et al.*** (1997) found that the average time for men using warm air dryers was 17.0 seconds and 13.3 seconds for women. However, the study by Knights ***et al***. (1997) involving 292 subjects showed that men used warm air dryers for 15.4 seconds on average and women for 17.7 seconds. A survey on the "***Country Doctor***" website (2006) gives the average time for men using a warm air dryer as 20 seconds and for women as 16 seconds. Therefore, the drying time of 20 seconds for both sexes used in the present study is likely to be longer than the actual average time that the public uses warm air dryers and would favour them compared to towels so that any poor results from dryers cannot be explained by the drying time used in this study being too low. The drying time of 10 seconds used for the Dyson Airblade dryer was not based on observations of the public but on the manufacturer's recommendation as given on the dryer itself.

Using the three different growth media it was hoped to count most of the bacteria present on the subjects' hands before and after washing and drying. In addition, it was also hoped that information would be obtained about the incidence of the following types of bacteria in particular:

- ***Escherichia coli***, a bacterium found in the human gut and a good indicator of faecal contamination. Some strains are pathogenic and cause disease, sometimes severe, ***e.g***. O157. This bacterium produces large yellow colonies on Cystine-Lactose-Electrolyte-Deficient Medium (CLED).
- Other coliforms also grow on CLED. Distinction between normal commensals and pathogens would require further tests which were not done in this part of the study but any presence of coliforms is indicative of faecal contamination and poor hygiene.
- Acid from mannitol negative staphylococci and micrococci. The former can sometimes be pathogenic and cause disease. These bacteria grow on mannitol salt agar and are normal commensal inhabitants of human skin and nostrils.
- Acid from mannitol positive staphylococci. These were differentiated on mannitol salt agar by the production of yellow zones around colonies due to acid production and presumptively identified as ***Staphylococcus aureus***. This organism can be found on the skin and in the nostrils of healthy people but it is a common potential pathogen causing a toxigenic food poisoning, abscesses, boils and other problems. However, pathogenicity and antibiotic resistance vary greatly between different strains, which include meticillin-(methicillin-) resistant ***Staphylococcus aureus*** (MRSA), a common hospital-acquired infection. The presence of any type of ***Staphylococcus aureus*** on the hands of a worker in the food industry or medical field should be taken seriously as should any increase in its numbers caused by particular hand

drying methods.

The issue of warm air dryer hygiene is controversial. Some studies (Blackmore, 1989; Blackmore & Prisk, 1984; Gould, 1994; Knights ***et al***., 1993; Knights ***et al***., 1997; Ngeow ***et al***., 1989; Redway ***et al***., 1994; Redway ***et al***., 1995) have shown that warm air dryers are hygienically inferior to towels and may actually increase the number of bacteria on the hands after use. Other studies (Davis ***et al***., 1969; Gustafson ***et al***., 2000; Matthew & Newsom, 1987; Meers & Leong, 1989; Patrick ***et al***., 1997; Taylor ***et al***., 2000) have shown that there is little significant difference between the three hand drying methods. Only a few studies (Ansari ***et al***.,1991) have shown warm air dryers to be generally hygienically superior to paper towels. Yamamoto ***et al***. (2005) found warm air dryers reduced bacterial numbers if subjects held their hands stationary in the airflow rather than rubbing them which caused an increase but this method is likely to take longer to dry the hands. They also found that paper towels reduced the bacterial numbers on the fingertips more than warm air dryers; a result which agrees with the present study. However, their observation that paper towels did not reduce bacterial numbers on the palms is not in agreement with the results of other studies or the present one but may be explained by a different sampling method.

The large discrepancy between the results of different studies can invariably be explained by differences in the experimental protocols used, such as abnormally long drying times of up to 1 minute (when the average time used by the public is less than 20 seconds) and by the use of new dryers in laboratories, rather than regularly-used, and often contaminated, dryers in public washrooms. Used dryers are commonly contaminated and emit bacteria in their air flow (Redway ***et al***., 1994). It should be noted that a new warm air dryer and new Dyson Airblade dryer were used in a laboratory in this part of the study and that regular tests showed no significant numbers of bacteria in their air flows. Therefore, any increases in bacterial numbers after use of dryers in this part of the study must have been due to factors other than bacterial contamination of the dryers themselves.

It is generally accepted that the transmission of bacteria and other microorganisms is more likely to occur from wet skin than from dry skin (Gould 1994). This happens partly because of the ease of water transfer from one surface to another and partly because microorganisms prefer a damp environment and, therefore, may be in a better physiological state to colonize touched surfaces. The amount of residual water left on the hands of users after drying is directly related to the number of bacteria that are transferred by contact, the greater the amount, the more bacteria (Patrick ***et al***., 1997). Knights ***et al***. (1993) showed that warm air dryers in normal use do not dry the hands as thoroughly as either type of towel. Warm air dryers in normal use achieved only 55% dryness of the hands of men and 68% of the hands of women. In contrast, both types of towel in normal use achieved 93% or more dryness of the hands of both sexes. It is highly likely that the significantly poorer hygiene performance of warm air dryers compared to towels shown in this study is mainly due to the low drying efficiency of dryers and the consequent greater amount of water remaining on the fingerpads and palms of the hand after their use. However, there must be other factors operating on the bacterial load on the hands of users because although the Dyson Airblade dryer showed a similar drying efficiency to paper towels (see Part A of this study), its hygiene performance,

although better than the warm air dryer, was significantly worse than the two types of paper towel tested in this study. It is possible that paper towels work better because they frictionally remove dirt, grease, bacteria and skin squames from the hands whereas the Dyson Airblade dryer, like the warm air dryer, does not. The superior performance of paper towels over the two types of dryer in reducing the numbers of bacteria was shown with both the fingerpads and the palms of subjects.

The room temperature, the tap water temperature and the relative humidity varied in the laboratory from day to day (see ***Table 7***) but any effect that these factors may have had on the results were minimized by randomising the order of hand drying method tested and subjects used.

In this study both types of paper towel (PT 1 and PT 3) tested reduced the mean numbers of all types of bacteria tested on the fingerpads and the palms of subjects. The percentage mean reductions ranged from –44.6% to –91.5% for fingerpads and from –32.8 to –85.2% for palms. Reductions were shown with all types of bacteria on all 3 growth media. The majority of these reductions were significant suggesting that they were not due to chance alone but to the action of the towels.

The warm air dryer increased the mean numbers of all types of bacteria tested on the fingerpads and the palms of subjects. The percentage mean increases ranged from +114.1% to +414% for fingerpads and from +230.4% to +478.8% for palms. Increases were shown with all types of bacteria on all 3 growth media. The majority of these increases were significant, some highly so, suggesting that they were not due to chance alone but to the action of the warm air dryer.

The Dyson Airblade dryer increased the mean numbers of most types of bacteria tested on the fingerpads and the palms of subjects. The percentage mean increases ranged from +28.0% to +193.3% for fingerpads and from +9.1% to +82.2% for palms. Increases were shown with most types of bacteria on all 3 growth media, the only exceptions being reductions on the fingerpads of mannitol-negative bacteria and reductions on the palms of mannitol-positive bacteria. However, neither of these decreases was significant, whereas some of the increases were.

Comparisons of the after dry bacterial counts on the fingerpads of subjects using the paper towels with the warm air dryer and with the Dyson Airblade dryer showed that there were highly significant differences between the towels and both types of dryer, ***i.e***. the superior performance of the towels in reducing bacterial numbers was confirmed. Both types of dryer caused mean increases in the bacterial counts on the fingerpads of subjects but the Dyson Airblade dryer performed better than the warm air dryer in that the increases were not as great. Differences between the two types of dryer were less significant than for the towels compared to either dryer.

Results for the palms were similar. Comparisons of the after dry bacterial counts on the palms of subjects using the paper towels with the warm air dryer and with the Dyson Airblade dryer showed that there were significant differences (although not as great as for the fingerpads) between the towels and both types of dryer. Again, the superior performance of the towels in reducing bacterial numbers was confirmed. As for the fingerpads, the Dyson Airblade dryer performed better than

the warm air dryer in not increasing mean bacterial count on the palms as much but this difference was not significant.

Therefore, Dyson's claim that it is the "***most hygienic hand dryer***" are confirmed, especially for fingerpads and assuming that the term "***hand dryer***" refers to electric devices only because its performance in terms of the numbers of all types of bacteria remaining on the hands of users compared to paper towels was significantly worse.

Other observations

The temperature of the air flow from the warm air dryer was higher than that from the Dyson Airblade dryer which, unusually, uses unheated air (see ***Table 7***). The latter's air flow temperature was higher than that of the room because when air is forced through any orifice (in this case the slits of the dryer) its temperature rises. Neither type of electric dryer would produce temperatures high enough, and for long enough, to kill most bacteria.

The Dyson Airblade dryer was particularly noisy compared to all other methods of hand drying tested, including a warm air dryer which was obviously noisier than the paper towels. Several subjects commented on the noise level of the Airblade dryer and the decibel levels recorded in the laboratory and a public washroom confirm it (see ***Table 7***). The mean decibel level at 0.5 m is 94.1dB and in excess of that of a passing heavy lorry 3 m away. The mean decibel levels at 1.0 and 2.0 m are in excess of a typical busy street at 87.4 and 86.3 dB respectively. In washrooms with more than one dryer the noise level would be even higher and could constitute a risk to those exposed to it for long periods, such as washroom attendants. The two public washrooms tested for bacterial contamination in Part D had 8 Dyson Airblade dryers each. ***Table 7*** shows the decibel level recorded when 2 dryers were being used at the same time at a distance of 2 m as 92dB, the second highest recording taken and only being exceed by the noise level at 0.5 m.

However, assessment of the risk of noise is complex, involving average and peak levels, and the decibel scale is sometimes misunderstood, ***e.g***. an increase of 3 dB represents an actual doubling of the noise level. The Health and Safety Executive (2008) discuss using hearing protection devices for some environments with noise levels in excess of 85 decibels but length of exposure and the frequency of the sound must be considered in addition to the decibel level alone.

Any further discussion of noise is beyond the scope of this present study as is the claim that the Dyson Airblade consumes less power than a warm air dryer. In this study the two types of dryer had similar power consumptions (see ***Table 7***) but any cost savings would presumably be due to the fact that the Airblade dries the hands more quickly and is, therefore, not used for so long.

Part C: Potential contamination of other users and the washroom environment caused by paper towel, warm air dryer and Dyson® Airblade dryer.

Introduction

In this part of the study artificial contamination of the hands of subjects was used in an attempt to demonstrate and compare the potential contamination of other users and the washroom environment caused by the different hand drying methods tested: paper towel, warm air dryer and Dyson Airblade dryer.

A previous study at the University (Redway ***et al***., 1995) compared the anti-bacterial performance of textile towels and warm air dryers after artificial contamination and washing of the hands. It showed that towels were superior to warm air dryers in producing significantly greater reductions in bacterial numbers on the hands of subjects. This previous study used the bacterium ***Micrococcus luteus*** as the artificial contaminating agent. In a more recent study (2008, unpublished) the contaminating agent was changed to the yeast ***Saccharomyces cerevisiae*** and similar results obtained. The yeast proved a good model and better than the bacterium in being safer, more acceptable to volunteers, easier to detect on appropriate growth media and easier to distinguish from normal hand flora. Therefore, in this present study yeast was used to artificially contaminate the hands of subjects prior to washing their hands and drying them using different methods. Any potential microbial contamination originating from the hands of users that could contaminate other users or the washroom environment was demonstrated by the isolation of yeast colonies on agar plates positioned at varying distances from the different hand drying devices.

Methods and materials

1. 9 open Sabouraud dextrose agar [SDA] (Oxoid) plates were placed around the hand drying device (a paper towel dispenser, a warm air dryer or a Dyson Airblade dryer) at the following distances (m) from the device: 0.00 (directly below), 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00.

   With the paper towel dispenser and the warm air dryer, the test plates were placed on a bench surface 31 cm and 42 cm respectively below the device. Due to the different design of the Dyson Airblade dryer, the test plates were placed on a surface 40 cm below the bottom of the hand drying chamber.

2. 3 ml of ¼ st. sterile Ringer's solution was added to each of 4 Sabouraud dextrose agar (Oxoid) slope cultures of the yeast ***Saccharomyces cerevisiae***, which had been grown at 30^{o}C for 2 days, and mixed using a sterile Pasteur pipette to obtain an homogeneous cell suspension. The volume of the suspension was made up to 500 ml with sterile distilled water.

3. 50 ml of the suspension was used to wet the hands of subjects who were asked to use it to mimic washing their hands in water, spreading it as evenly as possible over both their hands using a wringing action followed by three shakes.

4. Two subjects (one male, one female) were then asked to dry their hands using one of the following four hand drying methods and for the times indicated:

   i) Paper towel 1 (PT 1): 2-ply 100% recycled fibre. 10 seconds.

   ii) Paper towel 3 (PT 3): 2-ply through-air dried (TAD). 10 seconds.

   iii) Warm air dryer (WAD). World Dryer Corporation, "***Electric-Aire***", Model LE48. 20 seconds.

   iv) Dyson® Airblade dryer (DAB). Model AB01. 10 seconds

   Subjects were allowed to take as many paper towels as they wished but only within 10 seconds and used the same drying behaviour each time. Similarly, subjects used the same drying behaviour each time for the WAD and DAB dryers but were stopped after 20 and 10 seconds respectively.

5. Plates were re-covered and incubated at 30^{o}C for 2 days.

6. The number of yeast colonies on each plate was counted. Other types of colony, if present, were ignored.

7. The experiment was repeated 4 more times for each subject making 10 runs in total.

8. The paired t-test was used to establish if there were any significant differences between the different hand drying devices in terms of the mean number of yeast colonies isolated at varying distances from them.

9. Controls: Sabouraud dextrose agar (SDA) plates were left open for 1 minute and at the same distances from each hand drying device as in Step 1 above with the electric hand dryers off. The warm air dryer's airflow was tested for the presence of yeast by holding SDA plates beneath it at a distance of 10 cm for 20 seconds. The Dyson Airblade dryer's airflow was tested by holding SDA plates in the air flow emitted from the sides of the device for 10 seconds.

   The two subjects were asked to firmly press the fingerpads of their ring, middle and index fingers onto the surface of SDA plates. A sterile swab moistened with ¼ strength Ringers solution was then used to swab the entire surface of each agar plate so as to spread and disperse any potential colonies and enable them to be counted more easily.

   Samples (0.1 ml) of the sterile distilled water and the Ringer's solution were plated out on SDA and spread using a sterile glass spreader.

   All plates were incubated at 30^{o}C for 2 days followed by their examination to count any yeast colonies present. Other types of colony, if present, were ignored.

10. Measurements were made of the distances between pairs of Dyson Airblade dryers in the male and female washrooms of a main line London rail station.

Results

Table 1
Mean number of yeast colonies isolated on SDA plates placed at varying distances from different hand drying devices used by subjects with artificially contaminated hands.

HAND DRYING DEVICE	DISTANCE (m)								
	0.00	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.0**
PT 1	4.0	1.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
PT 3	3.2	1.7	0.1	0.0	0.0	0.0	0.0	0	0.0
WAD	34.1	2.8	0.0	0.0	0.1	0.0	0.0	0	0.0
DAB	47.0	76.2	37.5	21.8	16.0	11.9	8.1	4.8	1.2

(N = 10)

Key to table:
SDA = Sabouraud dextrose agar; PT = paper towel (1 or 3);
WAD = warm air dryer; DAB = Dyson Airblade dryer.

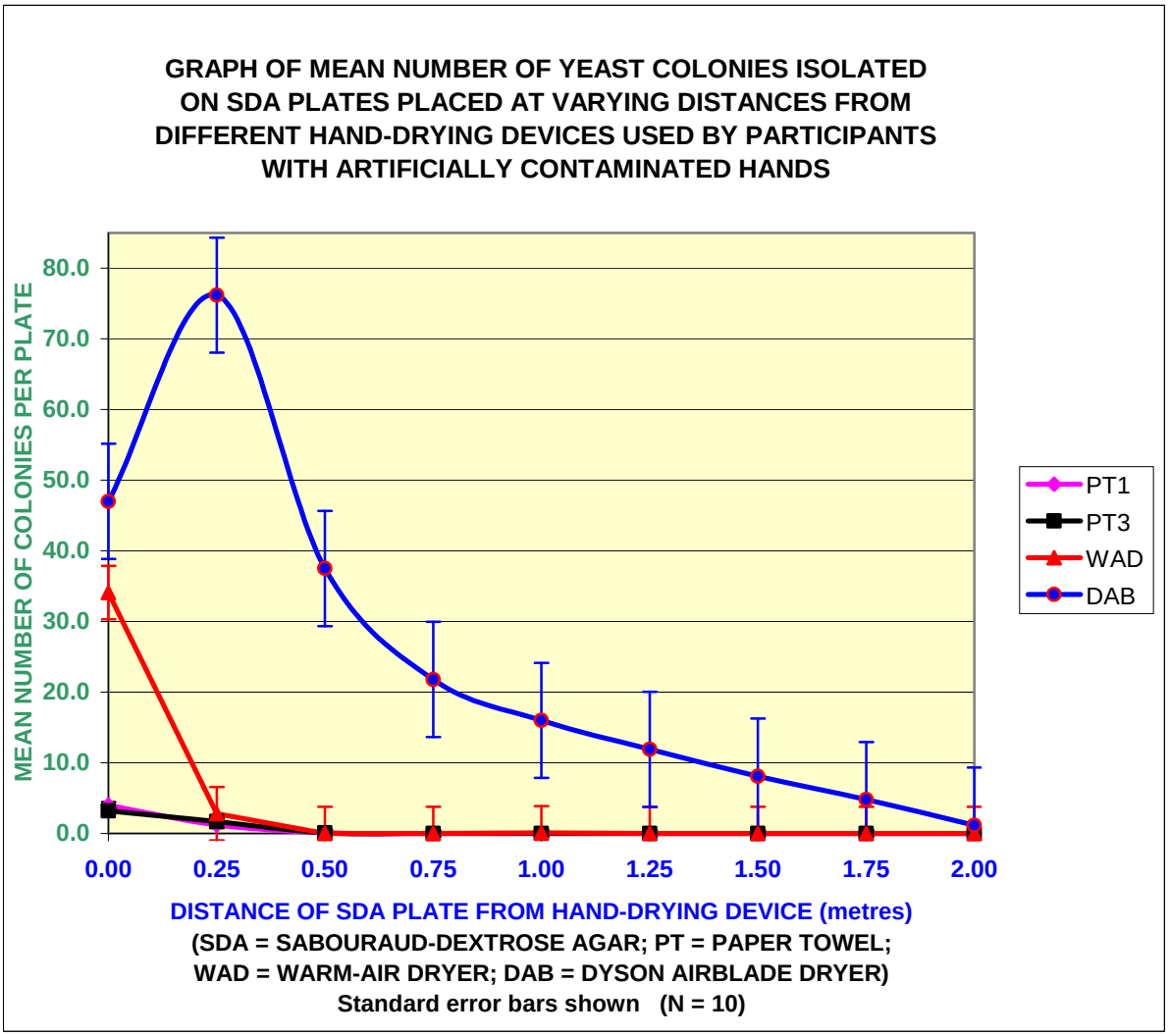
The results shown in ***Table 1*** are represented graphically in ***Figure 1***.

T-test results
Significant differences ($p < 0.001$) in the number of yeast colonies were found between both types of paper towel and the Dyson Airblade dryer at all 9 distances used. Differences between the paper towels and the warm air dryer were only significant at 0.00 m (directly below the device). The warm air dryer was significantly different from the Dyson Airblade dryer for all distances except 0.00 m.

Control results
Growth of yeast colonies was not observed on any of the control plates.

Measurements
The distances between 6 pairs of Dyson Airblade dryers in the male and female washrooms of a main line London rail station ranged from 0.36 metres to 0.45 metres with the mean being 0.39 metres.

Figure 1



Conclusions and discussion

The results suggest that paper towels are likely to cause considerably less contamination of other users and the washroom environment than the Dyson Airblade dryer which was shown in this study to disperse artificial hand contamination to a distance of at least 2 metres. Paper towels were better than the warm air dryer at 0.00 metres (directly below the device) but there was no significant difference at greater distances when their performances were similar and both significantly better than the Dyson Airblade dryer.

The mean distance between pairs of Dyson Airblade dryers in the washrooms tested was 0.39 metres. This distance is less than some of the distances used in this study and at which significant contamination from the hands of users of the dryer was detected. The implications are that if the hands of a user of a Dyson Airblade dryer were contaminated with a potential pathogen, it could be dispersed and transmitted to other users in the washroom, and the air and surfaces in the washroom. Any such contamination could be blown over the person using the adjacent dryer and could be inhaled by any persons present in the washroom.

The main reason for the large distances over which the Dyson Airblade spread the artificial contamination in this study is that, according to the manufacturer: "***Air is forced through two continuous apertures the width of an eyelash – creating sheets of air travelling at 400 mph.***" Air movements of 400 miles per hour (640 kilometres per hour) are sufficiently powerful to blow material in them over considerable distances as demonstrated in this study by the wide dispersal of yeast cells. This, coupled with the fact that this type of dryer emits air sideways rather than downwards (as with a warm air dryer) helps explain the results.

It is well known to microbiologists that air movements encourage the dispersal and transmission of micro-organisms and increase the chances of the contamination of materials or persons in any situation. This makes paper towels, where little air movement is generated, the most hygienic option tested in this respect followed by the warm air dryer and, lastly, the Dyson Airblade dryer.

Part D: Bacterial sampling of Dyson® Airblade dryers in public washrooms.

Introduction

Previous studies (Blackmore, 1989; Knights ***et al***., 1993; Redway ***et al.***, 1994) have shown that warm air dryers in public washrooms can be contaminated with various bacteria. This contamination can occur on inner surfaces, including air inlets and nozzles, and be detected in the air flow from warm air dryers. Such contamination can be transmitted to the users of warm air dryers by deposition on their hands and to all the users of a washroom through the air.

Dyson Airblade dryers are comparatively new and have not been widely tested. In this part of the present study the bacterial contamination of Dyson Airblade dryers in public washrooms was investigated.

Methods and materials

1. Sterile swabs were moistened with ¼ st. sterile Ringers solution and used to sample the inner surfaces of 8 Dyson Airblade dryers in the gents washroom and 8 in the ladies washroom of a main line London rail station. One swab sample was taken from each dryer by swabbing horizontally once along the back inner surface of the hand drying chamber, once along the front inner surface, once along the front air slit and once along the back air slit. Another swab sample was taken along the bottom of the hand drying chamber.

2. Swabs were returned to their sterile containers which were then removed to the laboratory for analysis.

3. Samples of the air emitted by the Dyson Airblade dryers were taken using open agar plates of three different growth media: Nutrient Agar (NA), Cystine-Lactose-Electrolyte-Deficient Medium (CLED) and Mannitol-salt Agar (MSA) held for 10 seconds at the side of the hand drying chamber in a vertical orientation whilst the dryer was running. Plates were removed to the laboratory for incubation and analysis.

4. Using gloves, the ends of the swabs were transferred to 3 ml of ¼ st. sterile Ringers solution and vortexed for 10 seconds to release bacteria adhering to the cotton wool of the swab.

5. 0.01 ml aliquots were then transferred to the surface of plates of three different growth media: Nutrient Agar (NA), Cystine-Lactose-Electrolyte-Deficient Medium (CLED) and Mannitol-salt Agar (MSA) and spread using a sterile glass spreader.

6. All plates were incubated at 37°C and examined after 1 and 2 days for bacterial growth. The number of colonies on each plate was counted and, where appropriate, distinction made between different types. Counts on plates which showed too many colonies to count were scored as 200, which is considered the upper limit for accurate counting. Counts on the inner

surfaces of the dryers were calculated as number of colony-forming units per square centimetre. Counts on 10-second air flow samples were calculated as number of number colony-forming units per agar plate.

7. Any colonies on MSA showing yellow zones were presumptively identified as ***Staphylococcus aureus*** and further tested using the coagulase test to confirm their identification by a positive reaction.

   Any confirmed colonies of ***Staphylococcus aureus*** were further tested for their sensitivity or resistance to meticillin (methicillin) by growth on Diagnostic Sensitivity Test Agar (Oxoid) with the addition of a 5 microgram meticillin disk. This showed if any of the isolates were meticillin-resistant ***Staphylococcus aureus*** (MRSA).

8. Colonies of interest on CLED medium were further identified using the Gram stain, the catalase test, the oxidase test and, when a member of the family ***Enterobacteriaceae*** was indicated, API20E (Biomerieux) biochemical test identification strips.

9. Control samples were taken of the inner surfaces and air flow of the laboratory-based Dyson Airblade dryer which had never been used in a public washroom. These controls were performed to help ascertain if any bacterial contamination found in dryers in public washrooms was due mainly to their location and usage rather than to any other factors.

10. The inner surfaces of the 16 Dyson Airblade dryers were sampled on two different days and at different times of the day making 32 samples in total. The air samples were taken on three different days and at different times of the day making 48 samples in total.

Results

Table 1
Mean bacterial colony counts on different growth media of samples from Dyson Airblade dryers in public washrooms and the laboratory.

SAMPLE TYPE	W/L	GROWTH MEDIUM		
		NA	CLED	MSA
INNER SURFACES AND SLITS (S) PER CM^2 *	W	171.4	85.3	127.2
	L	0.0	0.0	0.0
BOTTOM OF DRYING CHAMBER (B) PER CM^2 *	W	7002.5	7536.8	4745.1
	L	0.0	0.1	0.0
10-SECOND AIR SAMPLE (A) PER AGAR PLATE	W	14.1	19.8	9.7
	L	1.0	0.0	0.2

(N = 32 S swab samples; N = 32 B swab samples; N = 48 air samples; N = 5 laboratory controls)

Key to *Table 1*: W = public washroom samples; L = laboratory control samples; NA = nutrient agar; CLED = cystine-lactose-electrolyte-deficient medium; MSA = mannitol salt agar; * swab counts are minimum values due to upper limit of sampling method used (≤200 colonies per plate).

Table 2
Identifications and incidences of some of the bacteria isolated from samples of Dyson Airblade dryers in public washrooms.

SOURCE OF BACTERIA	IDENTIFICATION	*SAMPLE TYPE*	N	%
Human skin, hair, nasal secretions	***Staphylococcus aureus* ***	S	15	46.9
		B	25	78.1
		A	40	83.3
		T	80	71.4
	Other ***Staphylococcus*** species	S	29	90.6
		B	28	87.5
		A	48	100.0
		T	105	93.8
Human gut, faeces	***Escherichia coli***	S	1	3.1
		B	17	53.1
		A	8	16.7
		T	26	23.2
	Klebsiella species	S	1	3.1
		B	6	18.8
		A	4	8.3
		T	11	9.8
	Serratia marcescens	B	1	3.1
	Erwinia species	S, B	2	3.1
	Hafnia alvei	A	1	2.1
	Enterobacter species	B, A	2	2.5
Water, soil	***Pseudomonas aeruginosa***	S	8	25.0
		B	10	31.3
		A	6	12.5
		T	24	21.4
	Bacillus species	S, B	24	37.5
Various	***Chryseobacterium meningosepticum***	A	1	2.1
	Chryseobacterium indologenes	A	2	4.2
	Pasteurella pneumotropica	A	1	2.1

Key to *Table 2*: S = inner surfaces/slits; B = bottom surface; A = 10-second air sample; T = total (S+B+A); N = number of isolates (out of 32 S samples, 32 B samples, and 48 A samples); % = percentage of dryer samples that tested positive.

* No meticillin-resistant ***Staphylococcus aureus*** (MRSA) strains were isolated.

Conclusions and discussion

Bacteria were isolated from the inner surfaces of the hand drying chamber, the air outlet slits, the bottoms of the hand drying chamber and the air flows all 16 Dyson Airblade dryers tested on different days. The highest mean bacterial counts were obtained from the bottom of the hand drying chamber. This part of the dryer was observed to often be wet which would encourage bacterial colonization and survival and probably explains this part of the results. Also, swabs from the bottom were often visibly dirtier after sampling than swabs taken from the inner surfaces and slits. Bacterial counts on agar plates of a 10-second air flow sample were lower than either swab sample, as would be expected from the nature of the sample.

The mean numbers of bacteria isolated on agar plates from the air flows of the dryers in this study are similar to the results obtained for warm air dryers in previous

studies by the University of Westminster (Knights ***et al***., 1993; Redway ***et al***., 1994) but lower than those found by Blackmore (1989). This may be explained by differences in the frequency of use of dryers and on their location. This study sampled Dyson Airblade dryers in the washrooms of a very busy mainline London railway station and it would be expected that more bacterial contamination would occur than with dryers that are less frequently used.

Both the numbers and types of bacteria found to be contaminating the surfaces of the Dyson Airblade dryers in this study are similar to those found in another study (Redway ***et al***., 1994) associated with warm air dryers. The same types of bacteria have also been found in washroom environments by other workers (Mendes & Lynch, 1976). The sources of these bacteria are mainly human skin (***e.g. Staphylococcus aureus*** and other species), human gut and faeces (***e.g. Escherichia coli*** and other species of ***Enterobacteriaceae***) and water and soil (***e.g. Pseudomonas aeruginosa*** and ***Bacillus*** species). Although carried on the skin of a proportion of the population, ***Staphylococcus aureus*** is an important pathogen, especially if in a hospital environment and antibiotic resistant, ***e.g.*** meticillin-resistant ***Staphylococcus aureus*** (MRSA). No MRSA strains were found in this study but since its physical properties are identical to other strains of ***Staphylococcus aureus***, the results show that if MRSA was present in a location it would be likely to contaminate Dyson Airblade dryers in the same way and could be transmitted by touch or dispersed in the air.

The bacterial counts of the bottoms of Dyson Airblade dryers were particularly high, probably due to the water from users hands that collects in this area. Counts on the other inner surfaces of the dryers (inner surfaces and slits) were lower, probably due to the fact that these surfaces are generally drier than the bottoms. The bottom counts showed on average thousands of bacteria per square centimetre and the figure could be even higher due to the upper limit of the counting method used. These bacterial counts are higher than those found by Mendes & Lynch (1976) on the average toilet seat. Their study showed that about 80% of toilet seats in public washrooms had lower mean bacterial counts than the bottoms of the dryers sampled here.

Escherichia coli and the other species of ***Enterobacteriaceae*** isolated from Dyson Airblade dryers in this study demonstrate the potential for this type of device to become contaminated with human faecal material. ***Escherichia coli*** is a well known marker organism of such contamination. The detection of gut bacteria indicates the potential for this type of dryer to disseminate other more pathogenic types of ***Enterobacteriaceae*** (***e.g***. ***Salmonella*** and ***Shigella*** species) since the properties of all members of the ***Enterobacteriaceae*** are very similar. As with ***Staphylococcus aureus***, these bacteria could be transmitted by touch or dispersed in the air emitted by contaminated dryers.

It was not surprising that ***Pseudomonas aeruginosa*** was found associated with dryers in this study since it is commonly found in water but, like ***Staphylococcus aureus,*** it can cause severe problems in hospital environments and with certain types of patient. The species is generally resistant to many antibiotics but some hospital strains can be especially resistant and infections caused by them very difficult to treat. The results of this study suggest that the spread of such strains in a

hospital environment could be increased by the use of Dyson Airblade hand dryers.

The ***Bacillus*** species isolated in this study from some Dyson Airblade dryer surfaces probably have less significance with respect to human health. ***Bacillus*** species are commonly found in soil and the general environment. There are only two pathogens in this group, one causing anthrax and the other a toxigenic food poisoning, but the former is very unlikely to have been isolated in this study although the latter, often associated with rice-borne food poisoning, could have been. However, speciation of this group was not carried out in the present study.

The bacterial contamination of Dyson Airblade dryers could allow transmission of bacteria contaminating them if the user's hands touched the inner surfaces, the air outlet slits or the bottom of the hand drying chamber. It is possible to use these dryers without touching them but that will not be the case with all users. In Part B of this study some subjects were observed touching the bottom and sides of the hand drying chamber accidentally. Members of the public, especially those in a rush, could touch the inner surfaces of this type of dryer and their hands be contaminated by any bacteria present. This type of dryer may actually be worse in this respect than warm air dryers because putting the hands into a narrow slot is more likely to cause contact with the device than holding the hands beneath an air outlet nozzle.

However, even if the dryer is not touched, the results of this study show that bacteria are transmitted in the air flow and could contaminate the hands, other parts of the user, their clothes, other washroom users, or be inhaled.

Summary of main conclusions and discussion

Part A of the study shows that the drying efficiency of paper towels and the Dyson Airblade dry were equal. Both methods achieved at least 90% dryness of the hands within approximately 10 seconds and both were faster than the warm air dryer, which took over 4-times as long to achieve the same level of dryness. Therefore, Dyson's claims for the Airblade that it is "***the fastest hand dryer***" and that it "***dries hands twice as fast***" seem confirmed with the one proviso that it does not dry faster than towels but is certainly faster than other electric hand dryers such as a warm air dryer.

Part B of the study shows that both types of paper towel tested reduced the mean numbers of all types of bacteria tested on the fingerpads and the palms of subjects. As shown by other studies, the warm air dryer increased the mean numbers of all types of bacteria tested on the fingerpads and the palms of subjects. The Dyson Airblade dryer also increased the mean numbers of most types of bacteria tested on the fingerpads and the palms of subjects but the increases were less than with the warm air dryer. Therefore, Dyson's claim that it is the "***most hygienic hand dryer***" are confirmed, assuming that the term "***hand dryer***" refers to electric devices only because its hygiene performance compared to paper towels was significantly worse in all respects.

Part C of the study shows that paper towels are likely to cause considerably less

contamination of other users and the washroom environment than the Dyson Airblade dryer which was shown in this study to disperse artificial hand contamination to a distance of at least 2 metres, well within the range of adjacent dryers observed in a real washroom. Paper towels were better than the warm air dryer for contamination levels directly below the device but there were no significant differences at greater distances when their performances were similar and both were significantly better than the Dyson Airblade dryer. Therefore, Dyson's claim that it is the "***most hygienic hand dryer***" are not confirmed in this study with respect to its potential for dispersing bacteria.

In Part D of the study various bacteria were isolated from the surfaces and the air flows of all Dyson Airblade dryers tested on different days in public washrooms. The main sources of these bacteria are human skin, human gut and faeces, water and the general environment. Many of the bacterial types isolated are potential human pathogens. The results show that Dyson Airblade dryers can be colonized by bacteria and have the potential to transmit them to washroom users. Both the numbers and types of bacteria found to be contaminating the Dyson Airblade dryers in this study are similar to those found associated with warm air dryers. Therefore, Dyson's claim that it is the "***most hygienic hand dryer***" was not confirmed in this study with respect to its potential for contamination and colonization by bacteria.

The results of all parts of this study suggest that paper towels should be used in locations where hygiene is paramount, such as hospitals, clinics, schools, nurseries, care homes, kitchens and other food preparation areas. Warm air dryers and Dyson Airblade dryers should be carefully considered for these types of location because of their poorer hygiene performance and the increased likelihood of transmission of bacteria, including potentially pathogenic types, via the fingerpads and palms of the hand and their air flows. The performance of both the warm air dryer and the Dyson Airblade dryer was inferior to paper towels in all respects (drying efficiency, bacterial numbers on the hands, bacterial contamination of the air flow and surfaces of the devices, and transmission of bacteria in the washroom) with the one exception that the Dyson Airblade dryer is equal in drying efficiency. The Dyson Airblade dryer was shown to be superior to the warm air dryer in all respects except for similar bacterial contamination and greater transmission potential. Although representing considerable improvement over warm air dryers in speed, the Dyson Airblade dryer's overall performance, with the exception of drying efficiency, was significantly poorer than that of paper towels in all respects tested in this study.

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