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Secondary Transfer of Human Scalp Hair

REFERENCE: Gaudette, B. D. and Tessarolo, A. A., **"Secondary Transfer of Human Scalp Hair,"** *Journal of Forensic Sciences,* JFSCA, Vol. 32, No. 5, Sept. 1987, pp. 1241-1253.

ABSTRACT: Secondary transfer of hair occurs when a person transfers hair that is not his or her own to an object, place, or other person. Since it is possible that the perpetrator of a crime may have transferred hairs picked up from previous associations, secondary transfer can affect the value of associative hair comparison evidence. Nine experiments were conducted as a preliminary attempt to obtain information on hair transfer mechanisms and the role of some of the variables involved, as well as to get a preliminary indication of the extent and importance of secondary hair transfer. Indirect hair transfer mechanisms were found to be much more common than direct transfer mechanisms. This study further showed that secondary transfer of human scalp hair can and does exist in casework situations. However, the extent of secondary transfer was found to be extremely variable. Some factors that can affect the likelihood of secondary transfer in a given situation are discussed. The persistence of human scalp hairs on clothing was found to be quite similar to the persistence of extraneous fibers on clothing.

KEYWORDS: criminalistics, hair, transferring

Hair transfer can be of two types—primary and secondary. Primary transfer occurs whenever a person transfers his or her own hair to an object, place, or other person. This can occur either directly or by means of one or more intermediaries such as clothing. Secondary transfer occurs when a person transfers hair that is not his or her own to an object, place, or other person.

When it occurs as part of the physical evidence process, primary transfer of hair implies direct association between any combination of the following: accused, victim, crime scene, or weapon. On the other hand, secondary transfer of hair implies only indirect association. Assume, for example, that while Individuals A and B are drinking together in a bar, a primary transfer of A's hair to B's shirt occurs. If B then goes out and commits a crime, a secondary transfer of A's hair to the crime scene could occur, resulting in evidence indicating that A was at the crime scene, when in fact he had been nowhere near it.

It can therefore readily be seen that the possibility of secondary transfer should have some impact on the value of hair evidence. Gaudette [*1*] showed that the value of associative evidence is inversely proportional to the sum of the following three probabilities:

(1) the probability of incorrect association as a result of examiner error (β_E);

(2) the probability of incorrect association as a result of a coincidental match (β_C);

(3) the probability of incorrect association as a result of other factors such as *secondary transfer,* contamination, and deliberate planting of evidence (β_X).

Received for publication 18 July 1986; accepted for publication 3 Nov. 1986.

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Because of the implications to the value of hair evidence, the dearth of published research on the topic of secondary hair transfer is somewhat surprising. One reference to the existence and impact of secondary hair transfer was the discussion of a recent case [*2*] in which a secondary transfer of a hair from a suspect to a victim's body (by means of the investigating officer's jacket) caused a major homicide investigation to take an improper course. In a study involving laundered items, Simons [*3*] showed that secondary hair transfers can occur during laundering.

An understanding of secondary transfer of hair requires an understanding of hair transfer in general. The guiding principle behind physical evidence transfer is the Locard Exchange Principle [*4*] which states that whenever two objects come into contact there will always be a transfer of material. There has, however, been little published research dealing explicitly with hair transfer.

Peabody et al. [*5*] investigated the shedding of hairs into several types of headgear. They concluded that the number of hairs shed onto headgear varies with the type of headgear and the individual, and that hairs from headgear are most similar to hairs from known samples obtained by combing.

Quill [*6*] removed hairs from his clothing at the beginning and end of each workday for a 30-day period. He then compared the hairs removed to known samples from himself, his family, and his coworkers. He found that the few hairs recovered from his clothing during the day were contributed by himself and those in his immediate environment. Simons [*3*] found that although most human hairs are removed from items during laundering, some hairs are sufficiently persistent to remain on garments throughout the laundering process.

The transfer of other trace evidence materials such as fibers and glass has been studied more extensively. Pounds and Smalldon [*7*] conducted a number of fiber transfer studies with the aid of fluorescently labelled clothing. They concluded that fibers are being continuously transferred from the transferring garment to the recipient garment and vice versa during each contact pass. They found fiber transfer to be dependent on many variables such as areas of contact, pressure, number of contact passes, type of recipient garment, and fiber length. Lukaschek [*8*] determined that fiber transfer also depends on the method of construction of the recipient garment. Kidd and Robertson [*9*] added some other variables—texture of the recipient garment, fiber composition of the recipient garment, and fiber composition of the donor garment. Kriston [*10*] showed that fiber transfer results even from light contact without pressure.

In studying fiber persistence, Pounds and Smalldon [*11*] found time of wear to be the most important factor. The initial rate at which fibers are lost during wear was rapid. Robertson and Lloyd [*12*] found that with the passage of time, not only will fiber loss occur, but also some fibers will be redistributed away from the original area of contact. Robertson and Olaniyan [*13*] showed that some transferred fibers even persist on textile materials that have been hand washed, machine washed, or dry-cleaned. Pounds and Smalldon [*14*] stated that fibers remain on clothing by means of mechanical interactions with the surface of the recipient garment and that electrostatic forces are, at most, of only minor importance.

In the only fiber transfer study mentioning secondary transfer, Pounds and Smalldon [*14*] stated:

> Secondary transfer seems most likely to occur when environmental fiber contamination is considerable and the fibers are present in a weakly bound state. In the case of garments which are being worn these two conditions would be incompatible, since garments which have fibers primarily in the weakly bound state lost them very rapidly during wear. The small proportion of fibers which exist in the strongly bound state would be less likely to transfer.

and:

> Environmental or secondary fiber transfer would seem to be most important for contacts between clothing and horizontal surfaces rather than contacts between two sets of clothing. It would seem

difficult enough to establish contact via primary transference if the delay between the clothing contact at the scene of crime and a suspect being apprehended is days rather than hours.

In a study of glass transfer, Nelson and Revel [*15*] stated that the number of fragments retained by the clothing of a person breaking a window is dependent on the weave of the material, design features of the receptor garment, movements of the wearer, and time of wear. Brewster et al. [*16*] found that particle size and type of fabric influence the number of particles initially transferred, and that projecting particles onto loosely worn garments does not necessarily produce the same effect as projection onto tightly fitted clothing.

It is likely that many of the variables found to be important in fiber and glass transfer and persistence will also be important in primary and secondary hair transfer and persistence. To obtain information on primary and secondary hair transfer mechanisms and the role of some of the variables involved as well as to get a preliminary indication of the extent and importance of secondary hair transfer, nine experiments were designed and carried out.

Experiment 1

Method

Two individuals who were partially bald and had only very short grey hair were selected as subjects. Since Subject A worked as a uniformed guard at the front door of the laboratory, it was expected that he would have contact with a larger number of people during the workday than Subject B, a forensic scientist. Subject A's outer clothing (uniform) was taped with clear cellulose tape at the end of each of 50 workdays. In addition, on each of 10 workdays, he was asked to bring in 1 set of casual clothing he wore on the previous weekend. Subject B's clothing was taped at the end of each of 10 workweeks and his casual clothing worn on the preceding weekend was supplied and taped on each of 10 Mondays. Tapings from both subject's clothing were examined macroscopically and microscopically with the aid of a stereomicroscope. The number of hairs from each set of outer clothing that were not short and grey was recorded.

Results and Discussion

The results of Experiment 1 can be found in Tables 1 and 2. Since they could not have been their own, any hairs found on A's and B's clothing that were not short and gray must have been deposited on the clothing through either primary or secondary transfer from someone else. These hairs would then in turn all be a potential source of secondary transfer to other individuals. The results of Experiment 1 show that finding secondarily transferrable hairs is reasonably common. They also show that the extent of potential secondary transfer is highly variable, depending on such factors as the number of personal contacts one has in a day and the type of clothing worn.

TABLE 1—*Sets of outer clothing yielding unassociated hairs.*

Experiment	Subject	No. of Sets Examined	No. of Sets Yielding Unassociated Hairs	% of Sets Yielding Unassociated Hairs
1	A	60	39	65
1	B	20	8	40
2	T	40	2	5

TABLE 2—*Comparison of unassociated hairs found on work and casual outer clothing (Experiments 1 and 2).*

Type of Clothing	Number of Sets of Clothing	Number of Unassociated Hairs Found	Average No. of Unassociated Hairs/Set of Outer Clothing
Work	90	47	0.5
Casual	30	43	1.4

Experiment 2

Method

At the beginning and end of each of 30 workdays the clothing of one of the authors (A.T.) was taped. This person's casual clothing was also taped at the end of 10 evenings of social activities. Hairs removed from the various tapings were compared macroscopically and microscopically (comparison microscope) to the hairs present in a representative known sample of approximately 100 hairs obtained from the subject.

Results and Discussion

The results of Experiment 2, shown in Tables 1 and 2, further illustrate the highly variable extent of potential secondary transfer. The subject in Experiment 2 wore a lab coat over his clothing during part of the workday. Although the lab coat was also taped, smooth cotton fabrics are not good receptors of hairs. This may have contributed to the relatively small number of unassociated hairs[3] found in Experiment 2. The actual number of hairs not from the subject of this experiment could possibly be even smaller than the number of unassociated hairs since the design of Experiment 2 does not enable exclusion of the possibility that a so-called unassociated hair is really an atypical hair [*17*].

In that very few, if any, unassociated hairs were found in Experiment 2, the results of this experiment are in accordance with those of Quill [*6*] whose subject was a very clean, well-groomed individual. On the other hand, the results of our Experiment 1 present a different picture. This is likely because the subjects were not as fastidious as the subjects in Experiment 2 and Quill's work. Since clothing received in forensic science laboratories is generally not from individuals from clean environments, the results of Experiment 1 may more accurately reflect the potential for secondary transfer. That this potential is significant can be seen from the combined results of Experiments 1 and 2 in which a total of 90 unassociated hairs were recovered from 120 sets of outer clothing for an average of 0.75 unassociated hairs per set.

In Table 2, the higher average number of hairs found on the casual clothing is probably because it might not be as clean as work clothing and would be looser fitting, thereby making it a better recipient. As well, evening hour interpersonal contacts are more apt to be longer and more intimate. The hairs per set of casual clothing ratio could be expected to more closely resemble that found in actual casework.

[3]Unassociated hairs are defined as hairs which have forensically significant macroscopic and/or microscopic dissimilarities to all known samples to which they are compared.

Experiment 3

Method

Several human scalp hairs about 6 in. (15 cm) long were fluorescently dyed by immersing them in a concentrated aqueous solution of sodium fluorescein at about 100°C for 45 min followed by removal, rinsing with distilled water, and drying. One or more of these hairs was placed on the outer clothing of a volunteer subject who served as an "assailant" in a 1-min simulated assault on a volunteer "victim." A total of 43 assaults were conducted on a black mat in a large room. After each simulation, the subjects were asked to remain in position while a search was conducted for the marked hair with the aid of a portable ultraviolet (UV) light. In some assaults, 1 or more of the following experimental conditions was varied: (a) number of hairs placed on "assailant's" clothing, (b) location of hair placed on "assailant's" clothing, (c) identity of "assailant," (d) type of outer clothing worn by "assailant," (e) identity of "victim," (f) type of outer clothing worn by "victim," and (g) method of assault.

Results and Discussion

Table 3 shows the percentage of hairs found in various locations in Experiment 3. Over 80% of the potentially transferrable hairs were actually transferred to either the victim or the crime scene. The finding of the majority of the fluorescently labelled hairs on the mat is in agreement with Pounds and Smalldon's [*14*] observation that secondary fiber transfer is more important in contacts between clothing and horizontal surfaces than in contacts between two sets of clothing. Note that only a small percentage of hairs (3.5%) were sufficiently persistent to survive the simulated assault undisturbed.

Table 4 shows the influence of the type of clothing worn by the "victim" on the percentage of hairs transferred. It can be seen that wool garments worn by the "victim" lead to a much greater incidence of secondary hair transfer than do other types of garments. No great difference with respect to hair transfer was found between the polyester/cotton and the nylon materials.

Experiment 4

Method

The outer clothing of a volunteer "victim" was taped to ensure that no adhering hairs remained. A volunteer "assailant" whose outer clothing had been worn for a day and was *not* taped conducted a 1- to 1½-min simulated assault on the "victim." At the conclusion of

TABLE 3—*Location of fluorescently labelled hairs following assault in Experiment 3.*

Location	Percentage of Hairs
Victim	16
Assailant (different location)	8.5
Assailant (same location)	3.5
Mat	65
Lost	7

TABLE 4—*Influence of type of clothing on percentage of hairs transferred to victim in Experiment 3.*

Type of Clothing Worn by Victim	% Hairs Transferred to Victim
Rough textured wool	33
Polyester/cotton	17
Smooth textured nylon	20

the assault, the "victim" was asked to stand over a large sheet of paper and carefully remove his or her outer clothing. The paper and the various articles of clothing were placed in plastic bags which were then sealed. In the laboratory, the paper and clothing were searched visually and taped to recover any adhering hairs. The recovered hairs were then compared macroscopically and microscopically (comparison microscope) to known samples of about 100 hairs obtained from each of the "victim" and "assailant" and the number of unassociated hairs noted. A total of 24 simulated assaults were conducted in this way. In some assaults, 1 or more of the following experimental conditions was varied: (a) type of outer clothing worn by "victim," (b) type of outer clothing worn by "assailant," (c) identity of "victim," (d) identity of "assailant," and (e) method of assault.

Results and Discussion

Experiment 4 measured directly the number of unassociated hairs transferred as a result of a simulated assault. In 10 out of 24 simulated assaults, scalp hairs dissimilar to known samples from both the "assailant" and the "victim" were recovered from tapings of the "victim's" clothing, as seen in Table 5.

Since this clothing had been taped before the assault to ensure that it contained no adhering hairs, the unassociated hairs must have originated from the "assailant's" clothing and would be either secondarily transferred hairs or atypical hairs [*17*]. The results of Experiment 4 also show that when secondary transfer does occur, it quite often involves more than one hair, as was the case in four out of ten transfers of unassociated hair. The maximum number of unassociated hairs found in any one simulated assault was four.

In both Experiments 3 and 4, varying the type of assault was found to produce little difference in the extent of hair transfer.

Experiment 5

Method A

The outer clothing of a volunteer "victim" was taped to ensure that no adhering hairs remained. The "victim" was then asked to put a pair of nylon pantyhose on his or her head, followed by a plastic bathing cap. A volunteer "assailant," whose outer clothing had been worn for a day and was not taped, conducted a 1-min simulated assault on the "victim." At the conclusion of the assault, the "victim" was asked to stand over a large sheet of paper and carefully remove his or her outer clothing. The paper and the various articles of outer clothing were placed in plastic bags which were then sealed. In the laboratory, the paper and outer clothing were searched visually and taped to recover any adhering hairs. The number and location of recovered hairs was noted. This part of this experiment was designed to ensure that any transferred hairs would have originated from the assailant's clothing or hair. A total of eleven simulated assaults were conducted in this way. In some assaults, one

TABLE 5—*Results of Experiment 4.*

Assault No.	"Assailant"	"Victim"	Hairs Consistent with		
			"Assailant"	"Victim"	Neither
1	A	B	3	0	0
2	A	B	1	0	4
3	A	B	0	0	0
4	A	B	2	0	0
5	A	B	1	0	0
6	A	C	0	0	0
7	D	B	0	0	0
8	A	E	0	1	2
9	A	E	1	1	0
10	F	G	1	0	1
11	F	G	1	0	1
12	K	G	0	0	0
13	H	I	0	0	3
14	J	K	0	0	0
15	I	L	0	0	0
16	A	M	0	0	1
17	N	O	0	0	0
18	N	O	0	1	1
19	N	O	0	0	3
20	A	F	0	0	0
21	A	F	1	0	0
22	A	F	0	0	0
23	P	J	0	0	1
24	P	J	0	0	1

or more of the following experimental conditions was varied: (a) type of outer clothing worn by "assailant," (b) identity of "assailant," and (c) type of outer clothing worn by the "victim."

Method B

The same procedure as in Method A was used but this time the "assailant" was also asked to wear pantyhose and a bathing cap on his head. In this part of this experiment, any transferred hairs should have originated only from the "assailant's" outer clothing. A total of eleven simulated assaults were conducted in this way. In some assaults, one or more of the following experimental conditions was varied: (a) type of outer clothing worn by "assailant" and (b) type of outer clothing worn by the "victim."

Method C

The same procedure as in Method A was used but this time the "assailant's" outer clothing was also taped before the simulated assault. In this part of the experiment, any transferred hairs should have originated only from the "assailant's" head. A total of eleven simulated assaults were conducted in this way. In some assaults, one or more of the following experimental conditions was varied: (a) identity of "assailant" and (b) method of assault.

Results and Discussion

As can be seen from Table 6, it appears that much more hair transferred in simulated assaults originated from clothing than directly from the scalp (more than twice as much). It

TABLE 6—*Influence of mechanism on percentage of assaults yielding hair transfer in Experiment 5.*

Part	Mechanism	% of Assaults Yielding Hair Transfer
C	direct	36
B	indirect	73
A	combined	82

should be borne in mind that this experiment did not attempt to measure hair transfer from objects or horizontal surfaces. The results of Experiments 3 and 8 indicate that these would also be important sources of hair transfer. In can be concluded that in simulated assaults hair transfer mechanisms favorable to secondary transfer are much more important than the direct transfer from the scalp mechanism which virtually precludes secondary transfer.

The results of Experiments 4 and 5 confirmed the findings of Experiment 3 that wool materials are much more likely to be involved in secondary transfer of hair than either polyester/cotton or nylon.

Experiment 6

Method

Fluorescently dyed hairs were prepared as in Experiment 3. One or more of these hairs was placed on the upper front outer clothing of a volunteer participant. The hair was then pressed down lightly. After various lengths of time (1 to 8 h), the volunteer's outer clothing was searched using a portable UV light, noting the location of the hair. This experiment, which was designed to measure hair persistence, was conducted 50 times. The 10 volunteer subjects wore a variety of outer clothing and were involved in the normal daily activities in a forensic science laboratory.

Results and Discussion

The decay curve found for hair persistence, shown in Fig. 1, is remarkably similar to Pounds and Smalldon's [*11*] fiber persistence decay curves. After 8 h wearing, just 6% of the hairs remained. The persistence of hairs on wool garments was generally greater than on other materials.

Experiment 7

Method

Experiment 7 looked at the extent of unidentified hairs actually occurring in casework. Work notes from a total of 53 old cases from 4 different examiners were reviewed noting the average number of hairs found to be consistent with the victim, accused, and neither.

Results and Discussion

The results of Experiment 7 are presented in Table 7. The fairly high percentage of hairs found to be dissimilar to all known samples would not be entirely composed of secondarily transferred hairs. Other possible explanations for hairs in this group include atypical hairs

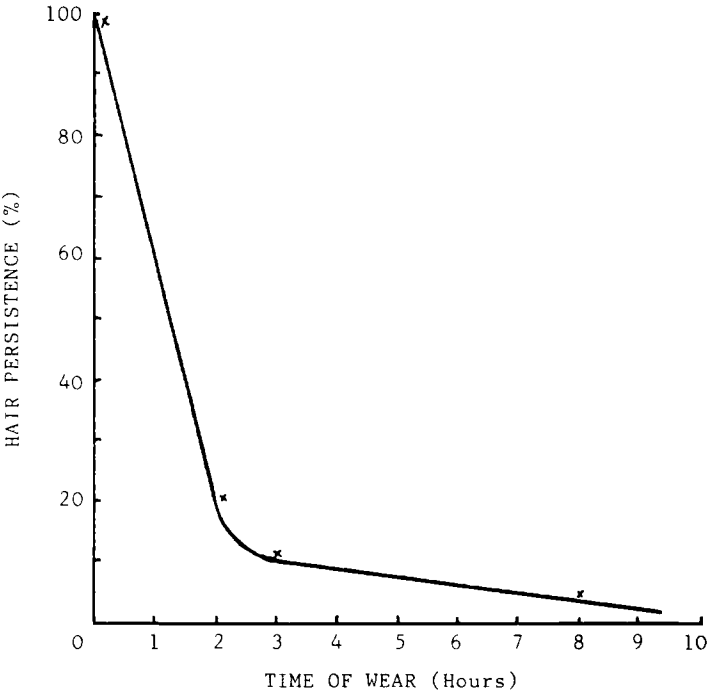

FIG. 1—*Hair persistence as a function of time of wear in Experiment 6.*

TABLE 7—*Results of Experiment 7.*

Hairs Similar to	Average Number of Hairs per Case	% of Total
Victim(s)	19.6	49
Accused(s)	7.6	19
Neither	12.7	32
Total	39.9	

[*17*], incorrect exclusions from known samples (Type 1 errors) [*18*], as well as primary transfer from persons from whom known samples were not obtained. Nevertheless, the results of this experiment indicate that secondarily transferred hairs can be encountered in casework. They also demonstrate the importance of requesting known hair samples from all persons who might reasonably be considered a source of questioned hairs.

The seemingly large differential between the average number of hairs matching the victim and the average number of hairs matching the accused in Experiment 7 is likely because generally more victim's clothing is received at the forensic science laboratory.

Experiment 8

Method

Experiment 8 was designed to provide an indication of the extent of secondary transfer from objects. One fluorescently dyed hair (prepared as described in Experiment 3) was

placed on the center back portion of the upper outer clothing of a volunteer. The volunteer then sat in a normal manner in an upholstered chair for 3 min, following which time the volunteer was asked to stand up while a search was conducted for the dyed hair with the aid of a portable UV light. In those cases where the hair was transferred to the chair back, a second volunteer was asked to sit in the chair for 3 min and the process was repeated. This experiment was repeated several times, varying: (a) the volunteers, (b) the type of outer clothing worn, and (c) the type of chair.

Results and Discussion

As shown in Table 8, the results of Experiment 8 indicate that hairs are readily donated from clothing to objects such as upholstered chairs. Once transferred, however, the hairs tend to be quite strongly bound to the upholstery fabric and do not transfer again as readily. Nylon clothing was found to be the best donor of hairs to upholstered chairs and the worst receptor of hairs from upholstered chairs. Wool was the best receptor but the worst donor. Polyester/cotton materials were neither strong donors nor receptors.

Experiment 9

Method

The same procedure as in Experiment 8 was used, but this time, attempts were made to deliberately set up a chain of secondary transfer, from Person A to a chair to Person B to a chair to Person C, and so on. Maximum chain length was measured.

Results and Discussion

Only those transfers involving a chain of at least 2 were counted. (Actually this was the great majority of the attempted transfers. To produce 50 transfers with chain lengths of 2 or more required only 59 attempts, that is, in only 9 attempts did the hair not initially transfer from clothing to a chair.) The results for the 50 chain experiments are given in Table 9. A chain length of 2 (clothing-chair) was the most common, with chain lengths of 3 (A's clothing-chair-B's clothing) and 4 (A's clothing-chair-B's clothing-chair) being occasionally found. The maximum chain length produced in the 50 attempts was 5 (A's clothing-chair-B's clothing-chair-C's clothing). Accordingly, it appears that secondary transfer is most often only 1 source removed from the original donor. This is likely because the type of garments which are the good donors of hair to upholstered chairs are also poor receptors and vice versa.

TABLE 8—*Hair transfer to and from upholstered chairs in Experiment 8.*

	% of Attempts Resulting in Transfer	
Type of Clothing	to Chair	from Chair
Wool	53	33
Polyester/cotton	50	7
Nylon	93	0

TABLE 9—*Results of Experiment 9.*

Chain Length	No. of Occurrences	% of Total
2	38	76
3	8	16
4	3	6
5	1	2

Conclusions

Hair transfer is a very complicated process, having many mechanisms and being influenced by many variables. Two types of scalp hair transfer can be identified—primary transfer and secondary transfer. Primary transfer can be either direct (from A's scalp to B's body, B's clothing, an environmental object, or a crime scene) or indirect (from A's scalp to A's body, A's clothing, environmental object, or a crime scene to B's body, B's clothing, environmental object, or a crime scene). Secondary transfer is by definition indirect going from A's scalp or A's body, clothing, environmental object, or a crime scene to B's body, clothing, environmental object, or a crime scene to C's body, clothing, environmental object, or a crime scene. The results of this study indicate that indirect hair transfer mechanisms are generally much more common than direct.

This study also shows that secondary transfer of human scalp hair can and does exist in casework situations. Because it is dependent on several factors, the extent of secondary transfer can be extremely variable. Table 10 lists some factors that tend to increase the likelihood of secondary transfer of human scalp hairs and Table 11 gives some factors which make such secondary transfer less likely to occur.

TABLE 10—*Some factors that seem to make secondary hair transfer more likely.*

1. Horizontal surfaces involved.
2. Suspect and/or victim wearing rough textured or wool clothing.
3. Unclean individuals with poor grooming habits involved.
4. Contact with objects used by several people (for example, upholstered chairs or car seats).
5. Involvement of an individual who had many personal contacts before the offense.

TABLE 11—*Some factors that seem to make secondary hair transfer less likely.*

1. A large number of hairs transferred (since it is unlikely that they would all be secondarily transferred).
2. Two way transfer (since it is unlikely that both would be secondary transfer).
3. The suspect and/or the victim wearing smooth textured clothing.
4. The suspect and/or the victim wearing tight fitting clothing.
5. The suspect and/or the victim wearing clothing that is neat and clean.

Since the probability of secondary transfer is one of the factors that must be considered in assessing the value of hair evidence, the results of these experiments further demonstrate the importance of the previously mentioned caution that in statistically evaluating hair evidence, each case must be evaluated on its own merits [*17,19*].

When secondary hair transfer does occur, the results of this study indicate that it will most often be first order secondary transfer (that is, only one source between the place where the hair is found and the original donor). Secondary transfer with two or more intermediates can occur but is apparently not common.

The persistence of hairs on clothing was found to be quite similar to the persistence of extraneous fibers on clothing, with only a small percentage of transferred hairs being sufficiently persistent to survive a day's wearing or a violent encounter such as an assault.

These experiments were conducted with Caucasian scalp hairs. Because they have different spatial configurations, it is possible that other hair types (such as Negroid or pubic hairs) might have produced somewhat different results.

Because of the complex nature of hair transfer and persistence, it should be emphasized that these experiments should be viewed only as preliminary work which will, hopefully, encourage other more detailed studies on the factors and mechanisms involved in hair transfer.

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