Head lice appearance and behaviour: implications for epidemiology and control

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Abstract

Detecting Pediculus humanus capitis, the head louse, in human hair directly affects the diagnosis and control of head lice. Pediculicide testing results and data collection for research purposes. Fine toothed combing is recommended as a diagnostic tool to improve visual detection and for the physical elimination of head lice.

This study evaluated the effect of louse and host factors on the grooming process by observing the appearance and behaviour of the parasite and its recovery rate during simulated grooming experiments. It was found that detection and removal of lice were greatly influenced by the behaviour and morphology of the parasite, choice of grooming tool and several hair factors.

These findings provide scientific explanation for broader clinical reports that undetectable louse numbers may be masked in the natural hair environment, thus affecting diagnosis and treatment and epidemiological surveillance. Inaccurate detection of head lice will flate home assessments and has important implications for louse control. To overcome the inherent complexities in detecting head lice, screening of populations at risk should be conducted by experienced health professionals rather than lay persons.

Introduction

As head lice have developed resistance to pediculicides , people are returning to physical methods such as shaving, haircutting, hand picking and fine-toothed combing to eliminate them . These methods were used to control louse-borne diseases well into the last century . However, except for shaving, little is known about the reliability of physical methods.

The rising prevalence of this communicable parasite worldwide warrants further basic research into its detection, transmission and control . A major factor limiting validity of studies is the diagnosis of infestation . Precise information on Pediculus humanus capitis, such as its appearance and ability to retreat in hair, is needed. Health personnel, and the public, must search the hair to identify, or physically retrieve live lice to confirm an active infestation.

Recently, the fine-toothed nit comb (‘detection-comb’ or ‘fin comb’) has been recommended to improve data collection, to check outcome of chemical treatments and to remove resistant lice as therapy . However, while this diagnostic tool can aid visual inspection and removal, rigorous examination shows that lice may nevertheless escape fine-combing . Yet, positive louse findings after presumed ‘all-clears’ during product testing and after community control failure have instead been attributed to reinfection. The higher prevalence in schoolgirls is also thought to be due to more frequent ‘attacks’ allowed by social contact , but this is not convincing .

Limited point prevalence studies and undetected infestations may affect not only the epidemiological picture but also public health control programmes . Institutional screening by trained nurses to control this parasite has declined . There is an incorrect assumption that diagnosis and elimination of resistant lice is reasonably straightforward for all laypersons to achieve .

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A number of the head lice were kept and nourished under controlled conditions\textsuperscript{13,14}, and their development through the life cycle observed. Better understanding of the appearance and behaviour of lice during all life stages will aid their detection.

**Grooming simulation**

Separate tresses of straight and very wavy hairs (20 hairs of 10cm length unless stated otherwise) were attached firmly, follicles together and uppermost, to hang from a vertical, white, slightly roughened plastic panel, overlying a white benchtop. Ten active lice (five adults, two third stage and three second stage nymphs) were placed midway up the tress being tested, each louse on a different hair shaft. Then a grooming tool (e.g. hairbrush or comb), applied above the lice, was angled downwards and swept once through the hair at 10cm per second, maintaining light contact with the plastic base (‘artificial scalp’) and using only a one handed action.

The number of lice retrieved from a tress of 20 straight hairs was counted after separately using: a hairbrush; a regular spaced plastic comb (about 1mm wide slots); a large widely spaced, broad-toothed comb (also called ‘afro comb’); a plastic fine-toothed ‘nit comb’ (Lady Jayne, Cork International); and an all metal fine-toothed comb. Each test was replicated twice more, removing up to 10 lice each time (both removed and non-removed lice were accounted for each time) and the efficiency of each grooming procedure calculated by dividing the total removed by the predetermined louse numbers. Thereafter, one detection tool was used to compare retrieval rates with various hair configurations (again using three tests except where stated otherwise). Louse behaviour relevant to grooming was also studied (with aid of macro video footage).

**Results**

**Louse appearance and host perceptions**

Head lice were experimentally reared to a second generation on two occasions. Measurements were taken of the first, second and third nymphal stages (instars) and adult stage, and the lengths of their intact exuviae (moulted exoskeletons) shed after each nymphal stage (lice and exuviae: total = 85) (Table 1).

The newly hatched creamy first instar, at little over half of 1mm can hardly be seen with the naked eye. It is exceedingly well camouflaged in the natural environment of skin flakes, debris, etc. Experimentally hatched lice moved along the hair shaft in both directions. They left the hair wherever it touched another surface, presumably to search for a first meal. They walked along artificial surroundings, clung tightly to cloth and climbed adjacent hairs. Although busy, their travel was awkward, and they did not turn quickly on the end of a hanging hair to get back to the follicle, as mature lice instantly

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**Methods**

**Preliminary biological investigations**

Over 10 months, 282 live Pediculus humanus capitis were donated by various people for identification and study. The number and life stages generally depended on removal technique: scratching and hand picking found the larger lice, while many younger stages were recovered by fine-combs, rarely by hairbrush. Many small lice could be counted only after painstaking teasing from hair debris, lint, far corners of containers or each other’s bodies. Few matched hair colour, many were translucent, and others appeared dead until brushed directly with a hair. These observations strengthened the hypothesis\textsuperscript{4,5} that retrieval (‘recovery rate’) of lice from hair (i.e. diagnosis) depends on complex interacting factors arising from both the parasite (e.g. its morphology and behaviour) and the host (e.g. louse habitat, host grooming and examiner experience).
Figure 2. Adult head louse feeding (magnified x40 approximately).

Table 1. Full body lengths (head to abdomen) of head lice life stages and corresponding exuviae (exoskeletons) (total = 85).

<table>
<thead>
<tr>
<th></th>
<th>1st Instar</th>
<th>2nd Instar</th>
<th>3rd Instar</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (mm)</td>
<td>0.63</td>
<td>1.1</td>
<td>1.7</td>
<td>2.6</td>
</tr>
<tr>
<td>Range (mm)</td>
<td>0.57-0.77</td>
<td>0.90-1.2</td>
<td>1.4-2.0</td>
<td>2.1-3.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1st exuvia</th>
<th>2nd exuvia</th>
<th>3rd exuvia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (mm)</td>
<td>0.88</td>
<td>1.3</td>
<td>1.9</td>
</tr>
<tr>
<td>Range (mm)</td>
<td>0.68-0.99</td>
<td>1.1-1.5</td>
<td>1.8-2.0</td>
</tr>
</tbody>
</table>

Apart from eyes and gut, the insect may appear thin and shadowy to the naked eye between feeds. Although obvious when moving on a white background, it blends in among hair shadows, louse faeces, darker coloured eggs and debris.

The longer, oblong third instar and adult are more distinct, but may still blend in with hair tresses. Biting and crawling sensations on the skin were more noticeable when resting; these symptoms were in addition to pruritic papules and crusts that developed after long-term exposure to louse bites.

Effect of grooming tool, hair type, length and number and repetitive combing on retrieval

All lice in three replications (100%, n=30) were removed from 20 straight hairs by the plastic fine-toothed comb, compared with only a few larger lice dislodged by the regular comb and none dislodged by the brush or broad-toothed comb (Table 2). The stiff metal fine-comb sheared away lice it contacted but failed to penetrate the entire 20 hair tress, explaining the missed lice unharmed in the hair. Because this fine-toothed metal comb was worse at picking up a wavy hair tress, the plastic fine-toothed comb was used as a standard detection-comb in subsequent experiments. Retrieved smaller lice were also easier to see on lighter coloured prongs.

did, but they also did not fall off. They appear to be hardly moving, are easily squashed and unrecognisable on a comb.

While resembling a small adult, the short abdomen with well developed legs gives the first instar a distinctive crab-like black appearance, although it has a much narrower thorax than the crab-like pubic louse.

Emerging from the first moult about 2 days after hatching, the second instar is still only about 1mm long. The colour of its more robust cuticle, like that of the mature stages, varies from nearly transparent to blonde, speckled grey to brown.
Table 2. Effectiveness of grooming tools on retrieval of 10 lice from a standard hair tress (20 straight hairs, 10cm).

<table>
<thead>
<tr>
<th>Grooming tool</th>
<th>% retrieval over 3 tests</th>
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<tbody>
<tr>
<td>Plastic fine-comb</td>
<td>100</td>
</tr>
<tr>
<td>Regular comb</td>
<td>10</td>
</tr>
<tr>
<td>Brush</td>
<td>0</td>
</tr>
<tr>
<td>Broad-tooth comb</td>
<td>0</td>
</tr>
<tr>
<td>Metal fine-comb</td>
<td>93</td>
</tr>
</tbody>
</table>

Only 20 per cent of lice were removed from the wavy hair (Table 3). Even this small 20 wavy hair tress entangled the detection-comb causing hairs to be ripped from the base, requiring reattachment for further tests. If the comb was slowed down or disengaged from tangles, more lice were seen escaping back into the hair. With the wavy hair shortened to 2cm, the comb moved more steadily and 73 per cent of lice were retrieved.

To gauge the effect of hair layering (tress thickness), 100 straight hairs were added to the original straight tress. Only 17 per cent of lice were removed. Unremoved lice were camouflaged more in the wavy and thicker hair tresses. Individual hair parting was needed to visually confirm the missing lice.

To see if repetitive combing could eventually retrieve all missed lice, 10 lice were again used in the 120 hair tress but sweeps were repeated rapidly in succession in an attempt to remove all lice. In three separate tests it took six, nine, and 11 sweeps to remove all 10 lice each time from this tress. Similar results were obtained on combing a long haired volunteer. Twelve rapid sweeps were required to remove all ten climbing lice inserted below a rubber banded ‘cordoned off’ 10cm section of 120 hairs.

Louse behaviour and mechanics of grooming and dispersal

It is believed that head lice survive only near the scalp and that they can be removed by grooming of any hairstyle. In this study, head lice commonly settled among hair roots of the test tresses as they do in real life. However, they also took refuge in knots, not always climbing back up when disturbed. When distant from the roots and undisturbed, some lice crawled downwards (distally) and directly across to the board (the artificial head). They usually returned via hairs to the follicles, but some settled on or behind the shadowy edge of the board. If motionless hairs were touching the skin, lice walked freely across, then test probed the skin before feeding normally.

While in thick hair underlayers, but not caught outright by fingernail or grooming tool, several evasive behaviours were observed:

- Accelerating to as fast as 1cm/sec towards the follicles.
- Clambering down, as well as among, hair shafts to escape.
- Crouching closer to the hair shaft if pressed from above then ‘bobbing’ back up afterwards.
- Rotating crab-like around hair shafts to avoid dislodgment, before resuming crawling up the hairs.

They also repeatedly escaped from hairs that had been pressed together between the fingers or comb teeth.

Due to their crab shaped limbs and feet (tarsi), even dead lice appear ‘attracted’ to hairs or the woven or looped threads of cloths, although they are easily shaken or brushed off. By contrast, live head lice did not fall off clean hairs no matter if shaken or blasted with air. They successfully crawled over ‘retentive’ surfaces depending on texture (fast on linen, fumbling over towelling). From a smooth benchtop live headlice were easily dislodged by wiping with a cloth to which they then tightly clung.

Thus, aside from their ability to be retained due to their anatomy, clapping behaviour needs to be overcome to dislodge live lice. Both mature and newly emerged lice were seen to resist interference when already clinging to a hair or cloth – when a fine-comb tooth, fingernail or stiff fabric was applied gently, the louse shifted and pulled its legs back to resist separation, until more forcibly dislodged.

Magnified viewing of hair tresses illustrated how inadequate tools, and increasing host hair waviness, length and layering, further enhanced the parasites’ clapping and evasive actions. Without a direct point of application and continuous force, lice would either remain on, or indirectly return to, hair. For example, lice slid down the hair shaft as if on a fireman’s pole, only to resume crawling upwards as soon as a wide comb tooth or fingernail lost direct contact. Even dislodged lice returned via loose hair between comb teeth if the comb slowed on tangles or thicker hair layers before reaching the distal tips. Despite their fragility in the open, this explains
missed lice or their disappearance in thicker tresses after momentary observation or capture during real life grooming. During grooming, some lice were seen to shoot off the hair at high speed, an effect attributed to static electricity. One hundred and seventy two lice were tested separately to assess the effect of applying a force to a louse grasping a tautly held hair shaft; each louse flung off in unpredictable directions up to 1.8m. This was achieved not only using plastic comb teeth, but also slightly damp objects, fingernails and metal comb and nail file, grounded via the investigator holding them, thus ruling out static electricity as the cause. Conversely, if the hair hung loosely, then the same intervening objects could neither lever nor flick the louse off and the hair swung away with the louse. Thus, certain conditions need to be met to overcome frictional and dynamic forces to shear or flick lice from hairs.

Hair conditioner may facilitate combing by untangling hair, and by decreasing the frictional force needed for the clapping action described above, i.e. 'makes the hair slippery for the louse': 10 individually tested lice slid easily off a tautly held hair shaft coated with conditioner with little force applied. By contrast, control lice on dry hair held their position (until friction was overcome by shearing or flicking). Some immobilised lice trapped in occlusive substances made a complete recovery if rinsed and left to dry a few minutes later.

During three sweeps with ten different lice each time, a mean of 43 per cent were retrieved by the detection-comb from a 120 straight hair tress coated with conditioner. Thus, combining conditioner with fine-tooth combing had practical benefit; compared with the 'unconditioned' 120 hair tress in earlier grooming tests (Table 3), the reduced odds of retrieving lice in a thicker tress (compared with a 20 hair tress), were improved, although not fully restored.

Discussion
In 1947, based on louse counts after scalp shaving, Buxton cautioned that cursory head inspections may underestimate the presence of lice. Since then, this possibility has hardly been investigated. Currently, public health approaches imply that self inspection and combing for resistant lice are feasible for all hairstyles. If diagnosis is unreliable, then research methods, the course of infestations, treatments, epidemiology and control strategies for this communicable disease need review.

This study attempted to identify and roughly gauge the contribution of crucial factors influencing diagnosis, by observing the parasite and conducting simple comparative grooming tests in fixed hairs. Major confounders of product trials and epidemiological studies (e.g. not knowing life stage sizes or true louse numbers in the hair, adjunctive louse grooming by parents and uncontrolled reinestation) were avoided.

Together with recent field studies, this study explains how parasite and human factors interact to greatly decrease the odds of finding all lice in the hair. Accuracy will vary for each case examined, diminishing with hair factors that obstruct combing. This also means that physical eradication of lice (without shaving) is more difficult than previously thought.

Louse appearance: morphology
Although critical to diagnosis, there seem to be no records of the size (body length) ranges for the three nymphal (instars) and adult head lice stages. As expected for Pediculus, the experimentally reared head lice showed a divergence of life stage sizes as the sexes develop. All the collected intact exuviae fell between the defined life-stage ranges and measurements of the reared lice were consistent with other lice taken direct from the scalp (n=39).

Head lice are rarely described under 2-3mm, yet this study suggests that most of a developing louse population is much smaller. One century ago, the first instar of P. capitis (the head louse) was illustrated as 1mm in length. This correlates with second instars found here.

Pediculicides should kill all lice at application. Even if strains here are small, without prior description of size ranges and appearance to compare with, pediculicide trials claiming to differentiate reinestation from failure are questionable. Also, the first instars (expected initially from unskilled eggs) referred to in non-ovicidal product trials could be confused with the more visible second instar survivors.

The barely visible sizes and appearance (e.g. near transparent lice) described here also challenge the current practice to ignore long-term egg deposition and symptoms, and assume an 'all-clear' if active lice are not found after treatment. Confirming active lice before commencing treatment is understandable. However, after treatment, a window of false negatives during which undetectable louse stages rebuild is possible.

Louse behaviour and the hair environment
Head lice are clearly adept at climbing hair shafts, and seeking nearby shadow. Therefore, using a bright light, magnifying lens and repeated dry hair parting in a systematic search of the fixed area near the scalp is useful to identify live lice settling at the hair roots and any new deposition of eggs close by. However, bulky hair hides residual lice. The louse
behaviours observed in this study contradict the generalisation that head lice away from the scalp are vulnerable. Healthy lice stray throughout the hair, creating a formidable large surface area for the examination and grooming required to ensure no lice are missed.

Contrary to having a 'precarious' hold in the hair, lice were observed to be well protected in their ideal habitat. Their tenacious clamping and evasive actions have to be overcome by a precisely directed and adequate shearing force. Effective dislodgment and removal requires a tightly slotted comb relative to louse size and one that is unrestricted by thick or tangled hair. For some hair types, this would be difficult to achieve. Even lubricated straight hair, if long, can knot on combing.

Effect of grooming tools
General hair care tools, ie hair brush, broad-toothed and regular comb, remove no or relatively few lice because they cannot create an effective shearing action. Some wild lice used for study had already survived pediculicides and grooming, without obvious damage, and resumed normal (including reproductive) behaviour. Thus, contrary to repeated advice otherwise, ordinary grooming itself is not a satisfactory louse control measure.

Both types of fine-toothed combs tested were roughly 10 times more effective at removing lice than an ordinary comb which is clinically useful. However, the recommendation that metal fine-toothed combs are better than plastic or vice versa, overlooks the individual's need to groom a reasonable amount of hair painlessly, and without missing lice constantly, whatever the comb material. While the benefits of a metal comb removing or crushing eggs close to the scalp were not tested, there would still be the need to eliminate any wandering lice that could otherwise replenish egg numbers daily.

Effect of hair characteristics
Compared to a straight hair tress, only one fifth of the lice in wavy hair could be removed by combing. Scalp sensitivity, and the unavoidable tendency of some hair types to snag and be pulled out repeatedly, even when using a more flexible comb, may prevent detection-combing altogether. Substantially shortening the hair allowed better louse removal and easier combing. Conversely, longer tresses are more difficult to comb and might have further undetected lice. However, even a relatively short hairstyle with straight smooth hair could limit access to lice; as the number of hairs in the test tress was increased, the ability to retrieve lice decreased. The laboratory findings support observations that, for some people, only shortened and 'thinned' hairstyles assure compliance and adequate detection and control of lice.

The entire scalp contains about a thousand times more hairs than the 120 hair test tress. Thus, this study confirms the pre-study expectation that, even using an efficient detection-comb, there is a strong likelihood of widespread false negative results in head lice diagnosis and, by the same token, widespread eradication failures. In particular, the more hair per louse to hide in, the more difficult it was to visually confirm the lice (even mature stages) that had escaped detection-combing. Thus, modern product and epidemiological studies could be under-diagnosing carriers.

Furthermore, the inter relationship between the variables of hair lengths, thickness (number in tresses overlaying scalp), and wavy (or any tangly) hair types strongly suggests that lice accumulate unrecognised at markedly different rates in different hair types and styles, irrespective of detection-combing method. Hairstyle, in modifying access to the louse, may alone skew success and failure in comparative trials, and may also play an extremely important role in epidemiology.

Epidemiology
A composite of hair factors, not just long hair, has recently been observed to hinder accurate louse retrieval in the community. Long or heavy hair has long been linked with higher infestation rates (both higher parasite burden and relatively higher prevalence) within the general louse affected population. Considering that lice may wander throughout hair, this is not unexpected. Although lice return regularly to the scalp, waist length hair has about 100km of hairs needing to be checked and cleared of lice to ensure a cure.

However, study populations without obvious long hair trends, and the frequent finding that females, even those with short hair, have higher prevalences of head lice, caused disagreement over the last few decades. Hair shortening and hair factors have since been largely ignored. Instead, social contact between girls or hormones have been tentatively suggested for presumed higher susceptibility. More recently, the link between higher infestation and longer hair has been reconfirmed which could have been missed earlier due to confounded data collection or analysis. The strong possibility of inaccurate diagnosis supports this. However, higher prevalence in girls and chronic cases deserve more explanation; the results of this study provide some insight.

This study does not refute that when lice are present, some people are more likely to catch them, particularly children and their mothers via unavoidable close contact. It also does not suggest that some hairstyles attract lice. The hair factors
identified here, together with human behaviour, might explain the higher prevalence in schoolgirls and anomalous subgroups on the basis of longer infestation periods.

Firstly, females are less likely to rapidly cure head lice by shaving as males do. Thus, true incidence (attack frequency) of infested males would be missed and female incidence assumed greater in isolated point prevalence studies. Secondly, females keep long hair or thickly layered 'short' hair. Once past the length of a male crew cut, hair shafts may bend over other hairs due to weight and structure. Thus, even a female 'bob' haircut at the collar, unlike an evenly thinned 'short back and sides', has overlapping hairs increasing in the thousands. Thick tresses impede visual diagnosis, combing and removal of resistant lice.

Therefore, although long hair presents particular difficulties, anyone with hair thicker or longer than a close crop, regardless of age or sex, is at risk for late detection, missed chemical failures and persistent lice, as found in a recent study.

Because the parasites are elusive, hair factors that modify access to them may be far more influential than presumed immunological differences. This possibly accounts for variation within and between louse affected population groups while still explaining more usual indirect female and long hair associations. On the other hand, the latter associations caused by 'inaccessible' hair may be less evident in some prevalence studies (e.g. boys equally infested) when endemic lice cause repeated transmission within population groups.

**Conclusion**

Although more work needs to be done, the biomechanical investigations conducted, coupled with the minuscule size of this organism, support field reports that imprecise detection is a considerable problem and, also, that hair barriers (e.g. thick as well as longer hair) which prevent accurate detection, likewise hinder thorough louse eradication. Fine-combing with hair shortening is ideal for removing resistant lice.

Fine-combing may aid examinations, but in some situations visual inspection with optical aids will be more useful; such screening tools should be used alongside clinical judgement. For example, renewed egg deposition or patients' reports of distinct crawling and biting sensations may point to surviving hidden lice in thick hair.

Lice have shown a history of rapid development of resistance to all pediculicides and many product formulations themselves are unreliable. Prevalence and chronic conditions have risen noticeably since school based screening and rigorous manual methods (egg picking, fine-combing, hair shortening) were disregarded about 20 years ago. Because pediculosis is not self limited and can be caught repeatedly, long standing infestations due to late detection and eradication failures in close community groups will facilitate transmission. The study findings, thus, support the rationale for a traditional transmission prevention strategy in the form of expert screening to ensure early detection and completion of effective treatment.

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