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Analysis of the components of 'electric nets' that affect their sampling efficiency for tsetse flies (Diptera: Glossinidae)

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Abstract

The efficiency of electrocuting devices currently used for sampling tsetse flies (*Glossina* spp.) and similar insects, was studied in Zimbabwe by recording approaches, kills, and escapes, with video. The kill rate of an electrified netting screen increased with the discharge frequency of the device up to 200 Hz (ca the highest practicable frequency) reaching ca 90% at best. The same kill rate was achieved by an electrified black cloth target. However, 'two-choice' comparisons of electric nets and their components showed avoidance by the tsetse of the black mosquito netting between the electric wires, and even of the electric wires on their own, though probably not of the black metal frame that supported them. The proportion of tsetse avoiding a standard electric net was ca 27% in full sun, ca 40% in shade, implying an overall sampling efficiency of, at best, ca 65% at the optimum 200 Hz discharge rate in sunshine, and ca 40-50% with the 67 Hz nets used currently in Africa. Potential for improvements therefore lies mainly in reducing the visibility of the nets; suggestions are offered.

Introduction

Electrified nets and targets for sampling tsetse (*Glossina* spp.), first described by Vale in 1974, are now standard techniques used throughout Africa (see Vale, 1993 *et ante*). Vale (1974) originally estimated the efficiency of electric nets as 96-99%, inferring that they were effectively invisible to the tsetse, and therefore sampled completely objectively. However, video observation has raised doubts about this objectivity (Packer & Brady, 1990), revealing two sources of error that may lead to significant under-sampling.

The first lies in the high proportion of tsetse (40-50%) that are not killed when they hit the electric wires; the second, which compounds this, is that 15-20% of tsetse seem to 'see' the electric netting and avoid contacting it altogether. This latter source of error is particularly worrying, since it implies a behaviourally-based, and therefore varying bias in the sampling system. The two errors combined indicated that the 'standard' electric nets currently in use catch less than half the tsetse that approach them.

Clearly, there are shortcomings in the general technique that need to be identified and if possible removed. G. A. Vale (pers. comm.) has recently tested some of the aspects Packer & Brady (1990) drew attention to, in particular the discharge ('spark') frequency and the power of the electric grid. He found the latter to be of relatively little importance, but spark frequency to be crucial, with maximum efficiency achieved at a rate of about 200 Hz (i.e discharges at 5-ms intervals). We report here a parallel study in which we used video to record the behaviour of tsetse in relation to various components of standard electric nets and targets.

Methods

All observations were conducted at Rekomitjie Research Station in the Zambezi valley, Zimbabwe, during August and September 1992. Two species of tsetse were present, *Glossina pallidipes* Austen and *G. morsitans morsitans* Westwood (trappable in a ratio of ca 20:1). These cannot be distinguished as to sex or species on video, but are readily distinguishable by their flight characteristics from almost all other flies (see Gibson *et al.*, 1991 *et ante*).

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Electrocuting devices tested

Standard electrocuting grids were used, consisting of 8-mm-spaced high tension wires stretched across a 1×0.5 m aluminium frame painted matt black (Vale, 1974). They were powered by a 12 V car battery driving an inverter-transformer oscillator (the 'spark box') generating spikes of >25 kV lasting ca 250 µs (see Vale, 1974; Packer & Brady, 1990). The spark box used was adjustable for discharge frequency, but was set to discharge at a constant 0.018 coulombs.

We use the following terms. 1. *Electric grid* refers to a rectangular metal frame supporting two vertical arrays of vertical, high tension wires that constitute the killing apparatus (there is a ca 3 cm space between the two arrays into which may be inserted screens of netting or cloth). 2. *Electric net* (as used by e.g. Hargrove, 1980; Torr, 1990) consists of such an electric grid a with netting screen (terylene, mosquito netting type, of ca 70% transparency) inserted between the two arrays of wires and covering the same area as them. 3. *Electric target* (as used by e.g. Vale, 1974, 1993) consists of an electric grid with opaque black cloth inserted between the wire arrays instead of netting.

The devices tested were baited with CO_2 (at ca 20 l/min), acetone (at ca 500 mg/h), and two polythene sachets each releasing ca 400, 100 and 800 µg/h of, respectively, 1-octen-3-ol, 3-n-propylphenol and 4-methylphenol. This blend provides a reasonable surrogate for ox odour (Torr, 1990; Vale, 1993), released in generous quantities to maximize tsetse numbers.

Experimental protocols

All experiments involved simultaneous, paired comparisons between devices. Each comparison was made over two days, with four trials per day between 15.00 and 18.00 h, each trial consisting of one 22 min video recording. The positions of the devices under test were reversed between trials.

Electric nets

These were tested in the lay-out shown in figure 1A. Two synchronized cameras suspended ca 2.5 m up gave aerial views of the two test treatments. Each device under test was placed vertically, on a black velvet groundsheet to increase tsetse visibility (Gibson *et al*., 1991). The black cloth target (1×0.75 m) served to concentrate tsetse around the test area. The lay-out was designed with the test devices 'facing' onto the black target in the expectation that any tsetse departing from one test device would deflect to the target and then have an equal probability of returning to either of the test devices. Had the devices and target been in line (as is conventional) the risk was of a bias arising from 'circling' tsetse (Gibson *et al*., 1991; Vale, 1993) surviving a non-killing device only to be sampled inevitably by the matched killing device.

The standard control was a rectangular frame of galvanized steel wire the size of the inner dimensions of the aluminium frames used to support the electric grids of the test screens (i.e. ca 1.0×0.5 m). This wire was ca 3 mm diameter, which could probably not be resolved by the flies at distances greater than about 10 cm (=1.7° at the tsetse's eye; see Gibson & Young, 1991; Brady, 1972), and there was certainly no evidence on video that the tsetse 'saw' the wire. In any case, we assumed that the frame was visually 'neutral' in the sense that, while tsetse within 10 cm of the wire might respond to it, there would be an equal chance of them passing either side of it.

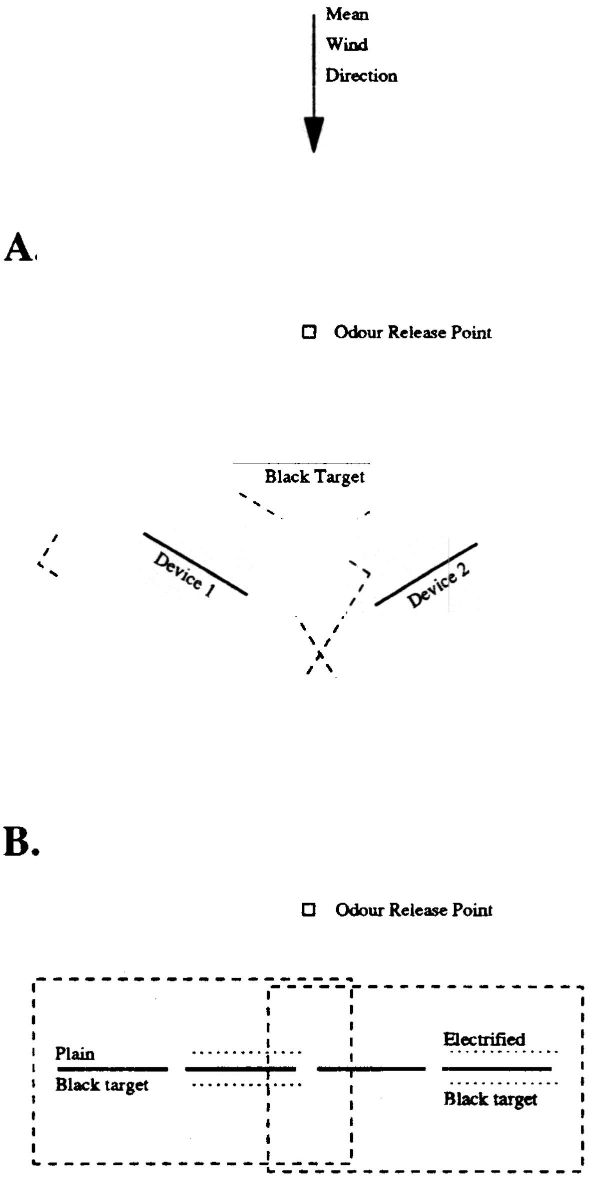

Fig. 1. Plan view of the experimental lay-outs. A, arrangement for the comparison of electric nets and their components; B, arrangement for observations on electric targets. Dashed boxes show approximate videoed areas; heavy black bars indicate top edges of rectangular black cloth targets (0.75 m wide in A, 0.5 m in B).

The control treatment was compared with a black aluminium frame on its own (i.e. without its electric grid), a complete electric net in full sunshine, and the same electric net in shade (provided by a moveable screen of cut branches). Finally, an electric net was compared with an aluminium frame on its own, and with an electric grid on its own. In addition, the killing efficiency of an electric net was measured at spark frequencies of 50, 100 and 200 Hz, and that of an electric grid at 200 Hz.

Electric targets

Other than in having the mosquito netting replaced with black cloth, the electric targets were identical to the electric nets tested above. They were compared only with similarly sized black cloth targets that were not electrified. Figure 1B shows the lay-out used; in effect there was a nearly solid 'wall' of black cloth 2 m long by 1 m high, with alternating 0.5 m wide electrocuting surfaces (whose positions were alternated between observations). Because of the visual impact of this wall, no additional black target was necessary; the spark frequency was 200 Hz.

Assessment of device performance

The numbers of tsetse visiting each device were assessed by counting the number of contacts on the wires of the electric grid or the numbers passing through the equivalent open space of the wire frame. The effect on tsetse was scored as follows: 1. *Killed* = tsetse dropped onto and stayed on the velvet groundsheet within an area that would normally have been covered with a sticky tray (i.e. ca 40 × 100 cm – see Packer & Brady, 1990) 2. *Recovered* = tsetse dropped into this 'sticky tray' area but flew off within 20 s (presumably few of these would have escaped a real sticky tray). 3. *Knocked clear* = tsetse dropped clear of 'sticky tray' area (and therefore would not normally have been caught or counted). 4. *Escaped* = tsetse flew off, apparently unharmed by contact with the electric grid.

The efficiency of electric nets (and electric grids) was then assessed as the 'kill rate' (= numbers in categories 1 + 2 as a proportion of the total number of grid contacts); and as the 'overall sampling efficiency' (= the numbers in categories 1 + 2 as a proportion of the number of tsetse passing through the control wire frame). Electric targets were assessed by kill rate (i.e. 1 + 2) only, with the numbers of kills compared with the numbers of contacts on the adjacent, unelectrified cloth target.

Statistical analysis

The fly counts were analysed in 5-min blocks (i.e. 4 per 22-min tape, disregarding the first 2 min for disturbance). The total number of contacts on, or flight through each device was scored, along with information on which camera position, day, time of day, and temperature. All results were then analysed using GLIM (McCullagh & Nelder, 1983), which fits models using a maximum likelihood method to explain variance in the test variable, similar to a least squares procedure. Variance due to camera position, day, time of day, and temperature were thus controlled for, so that the relative 'attractiveness' of the test treatment could be properly quantified.

Because the results are obtained as proportions of a catch, binomial error variance was assumed in the response variable. A log-odds ratio (or logit) link function was therefore used to control for non-normal and non-constant variance to allow linear fitting procedures (producing a curved line on de-transformation). Statistical significance was tested in terms of changes in deviance between maximum likelihood fits (i.e. as opposed to variance in a least squares model), so that significance was measured by χ^2, and differences between population estimates by t-tests.

Results and Discussion

Visibility of electric nets

There was no significant difference between the number of tsetse flying through the thin wire frame and the blackened aluminium frame of the same inner dimensions (table 1, 1st line). Thus the frame of a standard electric grid when painted matt black seems neither attractive nor repellent to the tsetse (although a shiny frame may have some negative effect, G.A. Vale, pers. comm.). On the other hand, when the aluminium frame was fitted up as a standard electric net, the numbers of tsetse that contacted it were only 73% of those 'contacting' (i.e. flying through) the thin wire frame at the same time; or 69% of those flying through the aluminium frame on its own. Moreover, this contact ratio was significantly worse (at only 60%) when the electric net was in shade – as it often would be in normal use.

When an electric grid on its own was compared with a full electric net (table 1, last line), it was apparent that the presence of the mosquito netting significantly reduced, by 18%, the number of tsetse contacting the electric wires. This reveals nothing directly about the overall relative visibility and avoidance of grids and nets, because there was no 'invisible' wire frame control comparison. However, as the 18% reduction is significantly less than the 27% difference between an electric net and the wire frame, some avoidance of the electrocuting wires on their own is indicated.

'Avoidance'

While table 1 thus provides clear evidence for up to 40% of tsetse behaviourally 'avoiding' electric nets, this may in fact be an under-estimate. Tsetse undoubtedly steer away from electric nets (Packer & Brady, 1990), but we identified

Table 1. Mean proportions of tsetse passing through or hitting various devices associated with electric sampling nets (expressed as mean of fly numbers in treatment B as a percentage of numbers in treatment A)

Treatment A	Treatment B	Mean B/A as % (±SE)
Wire frame		103 (±5)a
Wire frame		73 (±5)b
Wire frame		60 (±5)c
Aluminium frame		69 (±4)bc
Electric grid		82 (±3)d

All means except the first differ significantly from 100% ($P < 0.001$; t test); means not followed by the same letter differ by $P < 0.05$ or better; n = number of 5-min observations analysed.

Table 2. The 'kill' rate of tsetse hitting electric nets run at three different 'spark' frequencies, and on a bare electric grid (mean percentages (±SE) of tsetse in different categories; columns total 100%)

Fly category	Mean of flies per category			
	electric net run at			electric grid run at
	50 Hz	100 Hz	200 Hz	200 Hz
n				
(1) Killed				
(2) Recovered				
(3) Knocked clear				
(4) Escaped				

The 50 Hz and 200 Hz spark rates were tested in sunshine, the 100 Hz in shade; it is assumed this had no effect on how tsetse which hit the grid wires were electrocuted (see text); other details as in table 1.

'avoidance' only as the difference between the number of tsetse contacting an electric net and the number passing through the control wire frame at the same time. What we do not know is whether the electric net (which was certainly visible to the tsetse) did not also *attract* some tsetse, and so include in its catch tsetse not associated with its matched wire frame. Hence, 40% may well under-estimate the real number of tsetse who 'avoid' electric nets. [The use of an 'invisible' space as control against the tsetses' in-flight responses to the test devices is in all other respects a more objective technique than that used by Packer & Brady (1990), which involved the semi-subjective assessment of tsetse 'turning away' from the devices.]

Effects of sparking frequency

The efficiency of electric nets increased markedly with their sparking rate (table 2). The kill (i.e. categories 1+2) rose from 55% to 88% as the spark frequency increased from 50 Hz to 200 Hz; and there was a steep reduction in the escape rate (from 43% to 8%). Figure 2 shows the full form of the relationship, with the regression line ($y=2.58-0.119x$) explaining 71% of the deviance (it curves because it is shown de-transformed to allow the y axis to be read directly).

Intriguingly, the intercept of 93% at the theoretically 'infinite' spark frequency is significantly less than 100%. This implies that even at an extremely high sparking rate some 7% of tsetse would still escape; presumably this occurs because of tsetse bouncing away unscathed after contacting only one wire rather than the two required for a full electric shock. Interpolating a 67 Hz spark rate into the curve (at the cross), to simulate the performance of the 15-ms spark boxes that are most widely used in Africa, implies a kill rate of 69%.

Due to time constraints, the 100 Hz net was observed only in shade, whereas the 50 Hz and 200 Hz nets were observed in sunshine. It is unlikely that this affected the kill rates, however. First, because although shading increased behavioural avoidance of electric nets (table 1), there is no reason for that to have affected the way tsetse were electrocuted when they actually hit the grid wires (which is what table 2 records). Second, the relationship between spark rate and kill rate in figure 2 indicates no dip at 100 Hz that might imply such an effect.

Table 2 shows also the effect of removing the mosquito netting from an electric net, by testing an electric grid on its own at the 200 Hz spark rate. It is clear that the presence of the netting substantially improves the kill, by about 33% (i.e. from 55 to 88%). What the video revealed was that 66% of the tsetse actually passed straight through the electric grid (whether they were killed or not). This 55% kill rate of the 200 Hz electric grid was in fact about the same as that of a full electric net running at 50 Hz, except for the considerably greater number that fell clear of the sticky tray area, due mostly to the tsetse which flew through the grid at speed.

Overall sampling efficiency

Table 2 concerns the kill rate of tsetse that actually contacted the electric net. However, as table 1 makes clear, many tsetse managed to avoid contacting the net completely. Thus, only 73% of the tsetse that flew through the wire frame made contact with a sunlit net, and only 60%

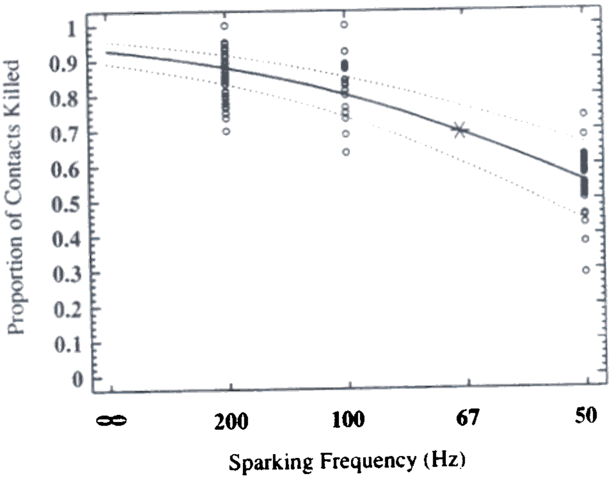

Fig. 2. Relationship between the mean proportion of tsetse contacting electric nets that were killed (ordinate=categories 1+2 in table 2) and the nets' sparking frequencies (abscissa). Each data point represents a 5 min observation. For derivation of regression line see text; dotted curves show 95% C.L.; cross shows interpolated 'kill' rate for the current standard 67 Hz electric nets.

contacted the shaded net, implying that the tsetse somehow 'see' the net and avoid it. This avoidance rate must therefore be allowed for in any estimation of the overall sampling efficiency of electric nets.

This is done in table 3, which shows the implied kill rates (categories 1+2 of table 2) adjusted for these avoidance levels in sun and shade (though the latter effect was directly measured only at 100 Hz). The data then indicate a best sampling efficiency for tsetse of around 65% with a 200 Hz spark rate in full sunshine, probably falling to around 50% when the net is in shade, and that the 67 Hz electric nets commonly in use today sample only 40-50% of the tsetse that approach them. These figures thus confirm, on the basis of a more objective technique, the earlier estimate of 43-49% sampling efficiency made by Packer & Brady (1990). It should be borne in mine, however, that these efficiencies are based on avoidance rates inferred from table 1 which may be under-estimates (see note on *Avoidance* above).

Electric targets

Electric targets firing at 200 Hz were compared only with the equivalent area of plain black cloth without electric wires (fig. 1B). There was no significant difference between the number of tsetse landing on the electrified and unelectrified targets, and thus no evidence that the electric wires in front of a cloth target were 'seen'. The mean kill rate on the electric targets was 86% (SE ± 2%), which is statistically indistinguishable from the 88% kill rate on electric nets sparking at 200 Hz (table 2).

Such black cloth targets are specifically designed to be 'attractive' and to elicit landing responses from tsetse; that is why they are treated with insecticide and used extensively in control programmes (Vale *et al.*, 1988). We therefore did not compare them with the open wire frame. In the absence of this comparison it is not possible to say exactly what proportion of tsetse avoided them, although it is certain that many do not land on cloth at first approach; they tend initially to 'circle' it. Thus, with equal areas of electric target and electric netting side by side, three-quarters of both *Glossina pallidipes* and *G. morsitans* are caught flying 'through' the netting wings (Vale, 1993, fig. 1).

Moreover, close analysis of several different kinds of video recordings of targets (with and without CO_2 present) indicated that tsetse very rarely fly in to land directly on the cloth from full cruising speed (ca 5 m/s, Brady, 1991). Nearly all of our hundreds of videoed target landings were made after a small local excursion around or near the target, often including landing on the ground nearby first. Comparable video observations of electric nets, on the other hand, show the tsetse usually hitting the netting at close to full speed. Clearly, electric targets and electric nets present very different stimuli to tsetse, with targets mainly killing them as they try to land from short local flights, and nets doing so as they try to fly through the netting.

Table 3. Apparent overall sampling efficiency of electric nets run at different 'spark' frequencies–based on the numbers of tsetse caught (categories 1+2 from table 2) multiplied by the 0.73 and 0.60 contact rates implied in table 1.

Situation of electric net	Mean % of available tsetse sampled, at 'spark' frequencies of:		
	50 Hz	100 Hz	200 Hz
Sunlit			**64**
Shaded			52

Figures in bold are data from conditions actually tested; the other figures are inferred on the assumption that spark frequency did not affect electric net visibility, and that shading did not affect electrocution (see text).

Implications for fly sampling

With electric nets, these sources of under-sampling will often not be a significant experimental problem, for example when observations are of relative catch rates, as in comparisons between target types (Vale, 1993), odour baits (Vale & Hall, 1985), visual stimuli (Gibson, 1992), or flight paths (Paynter & Brady, 1992). When the catch on one day needs to be strictly comparable with that on another, it will merely be necessary to replicate sufficiently to allow for the differential visibility of electric nets in sunshine and shade. With electric targets, avoidance is not a problem anyway, since the tsetse evidently land on them repeatedly.

On the other hand, when sample estimations assume 100% catching efficiency by electric nets (e.g. Hargrove, 1980), allowances for the ca 55% 'miss' level will have to be made. Similarly, as Paynter & Brady (1993) point out, experiments involving set-ups with rings of nets, which assume kill at first net contact (e.g. Torr, 1990), will also need more cautious interpretation.

Potential improvements

The increased kill rate with increased sparking frequency indicated in table 2 might be taken to indicate that one should use as high a sparking frequency as possible. However, the confidence limits to the regression line imply that there is only a marginal improvement to be gained by going above 200 Hz, and Vale has found a *decline* in the kill rate above 300 Hz, attributable to power loss at very high discharge frequencies (pers. comm.). A ca 10% escape rate is thus probably the best that can practically be obtained; it is, nevertheless, a considerable improvement over the ca 30% escape rate that occurs with the 67 Hz spark rates in common use today. An additional 5% (at 200 Hz) could also be gained by doubling the width of the sticky tray (to about 80 cm), so as to catch the category 3 tsetse that are 'knocked clear'.

However, by far the greatest potential for increased efficiency lies in recouping the 40-60% of approaching tsetse that apparently 'see' the net and avoid it. This requires making electric nets less visible. One possibility might be to suspend the wires of the electric grids horizontally, rather than vertically as is done at present. That should substantially reduce their visibility because tsetse mainly fly horizontally (Gibson & Brady, 1985). Horizontal lines thus provide their eyes with far fewer 'edge' effects than do vertical lines, and vertically striped patterns are strongly responded to whereas horizontal ones are not (Gibson, 1992). However, a contra-indication to this design would be if increased numbers of tsetse remain suspended between the horizontal wires, to short out the grid and burn up.

Since the mosquito netting in an electric net is highly visible to the tsetse, another approach would be to reduce this visual signal by replacing the present black netting with transparent mono-filament netting, or by removing the netting altogether. In the latter case, the increased number of escapes (45%, table 2) that arise from the 66% of tsetse that pass between the present 8-mm-spaced wires, could in theory be prevented by mounting the wires much closer together.

That is what Killick-Kendrick *et al.* (1986) did in order to catch sandflies (*Phlebotomus* spp.) (Diptera: Psychodidae). Their wires were assembled slightly staggered so that the negative grid was ca 1 mm upwind of the positive grid, to give a face-on spacing of only 2.7 mm between the wires, which allowed no sandflies to pass through (R. Killick-Kendrick, pers. comm.). However, their grids ran at only 2 kV, whereas tsetse grids typically run at over 25 kV, which might cause problems from increased 'arcing' if the wires were too close together. This could probably be alleviated by lowering the discharge voltage (G.A. Vale pers. comm.), or by increasing the degree of staggering, although the latter might then increase the chance of tsetse bouncing clear after hitting only one wire.

Finally, it may be possible to produce a tsetse-proof grid without mosquito netting by additionally staggering the two separate grids that normally sandwich the netting. This should allow construction of a four-layered array of wires whose average face-on spacing would be less than 4 mm, so that through flight would be virtually impossible. Grid visibility, already a significant factor (table 1), would necessarily be increased, however.

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