Analysis of Extrinsic Factor Associated with 379 Injuries Occurring during 34,236 Military Parachute Descents

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SUMMARY: A retrospective study of 34,236 consecutive static line parachute descents by trained parachutists, in which 379 were injured, is described. Injury rates associated with extrinsic factors were compared and then analyzed using logistic regression. A table describing the association with extrinsic factors, with relative risks, is at Annex A. The overall injury rate was 1.11% (1.11 injured per 100 descents). Rates from Helicopter (0.20%) and Balloon (0.13%) were low, and the study thus concentrated on aeroplane descents (injury rate 1.46%). Extrinsic factors associated with increased injury rates were carriage of equipment; wind speed and direction; numbers exiting and (on logistic regression) night descents. The overall rates appear higher than expected, possibly due to equipment weight potentiating the other factors. A prospective study is required to investigate the effect of equipment weight after which peace time training constraints should be reviewed. (Two approaches are described.)

Introduction

Within 5 Airborne Brigade a wide variation in annual injury rates during parachuting has been observed(1), from 0.60 to 1.2%, whilst in mass descents (in excess of 300 parachuting) rates have varied between 0% and 7.9%. This variation led to this study whose aim is to determine the extrinsic (or external) factors associated with injuries. Another study is examining intrinsic (or personal) factors.

Subjects and Methods

Parachuting in 5 Airborne Brigade forms the basis of the study. Data was obtained on the 377 consecutive static line parachute programmes (from aircraft, helicopters and balloons) prior to February 1989 involving 34,236 static line descents. All descents were by trained parachutists. Free fall descents were excluded.

Data was obtained from contemporary records. Personal data (including carriage of equipment loads) is recorded on flight manifests. The Royal Air Force Dropping Zone (DZ) party measure and record wind speed and direction (to abort parachuting if wind speeds are too high and by the aircraft to calculate when to release parachutists). Wind measurement is by a hand held undamped anemometer, calibrated in knots. The numbers exiting on each pass are obtained from aeroplanes and helicopters by radio from the aircraft, as is the run in direction of the aircraft and additional technical data. The aeroplane used is the C130 Hercules (Mk 1 with a capacity of 64 and the Mk 3 with a capacity of 90 parachutists). Both rear doors are used with simultaneous staggered exit. Various military helicopters were used. The parachute is the PX 1 Mk 4. Drop height is 244 metres (800 feet).

Data on the injured are collected by both the RAF and Now Commander Medical, HQ 1 Armoured Division, BFPO 32.

Medical DZ parties. A Parachuting Injury is defined as one caused during parachuting and attended to by the medical party on the DZ. Injured who choose to carry on and only report after the DZ party disperses are not recorded.

The extrinsic variables which it was thought could be associated with injury rate were the presence (or absence) of equipment; numbers exiting; dropping zone (DZ) night descent; numbers exiting the aircraft per pass on the DZ; the presence of wedge; wind speed; and wind direction. The data was analysed to determine whether the variables could account for the variation of injury rates seen in the individual parachuting programmes. The data was further analysed using logistic regression with the statistical package Generalised Linear Interactive Modelling (GLIM) (2). Via an interactive process a succession of models were fitted using the extrinsic variables described above. The continuous variables were first fitted then divided into a number of dummy variables, which through the interactive process were slowly reduced. Discrete variables were similarly treated. Each DZ was initially considered a discrete variable; those that did not explain any of the variance were combined. The estimates of the slopes of the individual variables were used to construct a table of predicted injury rates, and to estimate (from the odds ratios as observed rates are low) approximate relative risks (3) (at Annex A). Two other factors were thought to possibly be associated with injury rates but could not be analysed: wind gusts (insufficient data) and drop height (insufficient variation).

Results

There were 377 parachute programmes involving 34,236 descents with 379 injuries, giving an overall injury

ry rate of 1.11%. There were no fatalities and no missing data.

A breakdown of the casualty data is given in Table I. The rates for aeroplane, helicopter and balloon show a ten fold difference ($\chi^2 = 103.42$, 2 df, $p < 0.000001$). So great was the difference that it was decided to exclude the data on balloon descents from the subsequent analysis, and to use the helicopter data only for the evaluation of the effect of day and night descents, and equipment. One hundred and eight (38%) of the 285 aeroplane programmes resulted in injury.

Day and Night Descent

Night parachuting from aeroplane and helicopter accounted for 8.18% of the total descents. As the upper limit for wind speed for night parachuting is 9 knots (by day 13 knots) comparison was made with day programmes for wind speeds up to 9 knots. Table 2 shows the result. Night parachuting is associated with a higher injury rate. For aeroplane statistical significance was achieved on logistic regression (*vide infra*) with a relative risk of 1.8.

Carriage of Equipment

A total of 88.30% of all aeroplane and helicopter descents were made with equipment and Figure 1 demonstrates the relationship with injury rate. The rate with equipment from aeroplanes is 1.53% (95% Confidence limits 1.38-1.69%) and without equipment 0.15% (-0.06 to +0.35%). For helicopters the injury rate with equipment is 1.48% and without 0.06%. Both attain

Table 1
Summary of Casualty Data

	Number Programmes	Number Parachuting	Total Injured	Injury Rate	95% Confidence Limits
					Lower Upper
Aeroplane	285	25,093	366	1.46	1.31 1.61
Helicopter	27	2,023	4	0.20	0.004 0.39
Balloon	65	7,120	9	0.13	0.04 0.21
Total	377	34,236	379	1.11	

Note: Rates expressed in injuries per 100 descents.

Table II
Day and Night Injury Rates in Wind Speeds of 9 Knots and Less

	Number Programmes	Number Parachuting	Number Injured	Injury Rate	95% Confidence Interval
					Lower Upper
AEROPLANE					
Day	177	16,744	179	1.070%	0.91% 1.22%
Night	41	2,116	29	1.371%	0.88% 1.86%
HELICOPTER					
Day	21	1,668	1	0.06%	-0.06% 0.18%
Night	2	80	2	2.5%	-0.92% 5.92%

For Aeroplane $\chi^2 = 1.30$, 1df, $p = 0.25$
For Helicopter Fisher's exact test $p = 0.0059$

Fig 1. Association between Injury Rate and Carriage of Equipment.

significance (using Fisher's Exact Test for helicopters), with the rate for aeroplane descents without equipment almost down to that for Balloon descents (0.13%), when equipment is not carried. Using logistic regression the relative risk was found to be 7.14. Unfortunately no data is available to test any association between injury rates and equipment weight.

Relationship with Wind

Two associations between wind and injury rate were examined: speed and direction. Figure 2 indicates the relationship between injury rate and wind speed (in knot groupings). No significant difference is seen until 9 knots after which the associated injury rate rises rapidly. The χ^2 for the difference is 96.50 (4 df, probability < 0.00001). For the difference between the injury rate for 9-11 knots and that for the lower wind speeds the $\chi^2 = 41.86$ on 3 df, probability < 0.00001 . Fitting wind speed into the Logistic Regression model as a continuous variable suggested injury rate is associated with the square of the wind speed.

Fig 2. The Relationship between Wind Speed and Injury Rate.

Figure 3 shows the relationship between the injury rate and the wind direction relative to the aircraft. The relative wind direction is the difference between the aircraft heading (direction to which it is heading) and the wind direction (direction from which the wind is coming) expressed as degrees from 0 degrees to 180 degrees. (A relative wind direction of 0-60 indicates wind blowing towards the aircraft; 120-180 a tail or following wind; 60-120 a side wind.)

Based on groupings of 30 degrees the association between injury rate and wind direction is significant only for the difference for the tail wind 150-180 degrees (1.85%, 135 injured out of 7285 parachuting, 95% confidence interval 1.54-2.16%) and the remainder (1.29%, 230/17844, 1.13-1.46%), with χ^2 being 16.02 (5 df, $p=0.0068$). The difference between the other rates does not achieve statistical significance ($\chi^2=5.5$, 4 df, $p=0.2399$). On modelling it appeared that there was an interaction between wind speed and direction with wind direction over 120 degrees only being significant at wind speeds in excess of 9 knots. The estimated relative risks are shown at Annex A.

Relationship with Numbers Exiting the Aircraft

The injury rate rose in steps as numbers exiting in a single aircraft pass increased, with the rate for 1 to 22 exiting being 1.03% (103 injured, 9977 parachuting, 95% confidence interval 0.83-1.23%) 23 to 64 being 1.44% (162/11229, 1.21 - 1.65%), and 65 to 90 being 2.6% (101/3887, 2.10-3.10%). The differences were significant with χ^2 47.76, 2df $p<0.0001$. On Logistic Regression the significance between the two lower groups was not significant, leaving only greater than 64 exiting explaining some of the variation in rates. The relative risk is 2.80.

Presence of Wedge

An apparent association between the presence of Wedge (a pallet of equipment dispatched from the tailgate just before the parachutists exit) and higher casualty rates had been noted and this proved to be the

Fig 3. The Relationship between Wind Direction and Injury Rate.

case. However when stratified by numbers exiting the presence of Wedge was found not to be associated with injury rate. This was subsequently confirmed using logistic regression. (*Vide infra*).

Logistic Regression

Modelling indicated an interaction between wind speed and wind direction leading to the construction of the combined dummy explanatory variable (wind speed <9 knots any direction; 9 knots or over but not a tail wind; and a tail wind of 9 knots or over). The analysis of variance is shown in Table 3; all factors are significant except for the presence of Wedge.

Of the 14 DZs fitted, only 4 were significant: 2 being "protective" (Imber and Breakheart Bottom) and 2 "injurious" (Kenya and Feigheledean Down) compared to the other 10.

The formula of the selected model (95% confidence intervals in parenthesis) is:

Logit (of Injury Rate) = - 6.7660 (- 8.15 to - 5.38)
 + 1.9660 (0.58 to 3.36) If with Equipment
 + 0.5580 (0.15 to 0.97) If Night
 + 0.6688 (0.34 to 1.00) If >9 knots, no tail wind
 + 1.2510 (0.99 to 1.52) If >9 knots, with tail wind
 + 1.0290 (0.74 to 1.32) If >64 exiting
 + 1.7750 (1.39 to 2.16) If DZ in Kenya
 + 0.8938 (0.29 to 1.49) If DZ Feigheledean Down
 - 0.9886 (- 1.49 to - 0.49) If DZ Imber
 - 0.7002 (- 1.15 to - 0.25) If DZ Breakheart Bottom

At Annex A is a table predicting injury rates, based on the selected model, with relative risks.

The plot of actual numbers injured against predicted numbers using the selected model ("Goodness of Fit") is not shown but is adequate.

Table 3. Analysis of Variance of Factors in Logistic Regression Model.

Factor	df	Sum of Squares	Mean Square	Variance Ratio	Probability
Wedge	1	2.77	2.77	2.377	>0.05
Equipment	1	15.76	15.76	13.526	<0.005
Night	1	6.36	6.36	5.459	<0.05
Wind Speed/Direction	2	80.90	40.45	34.717	<<0.005
Number Exiting	1	41.51	41.51	35.626	<<0.005
DZ	4	93.00	23.25	19.955	<0.005
Residual	274	319.25	1.17		
Total	284	559.55			

Discussion

UK military parachuting has been adequately described elsewhere (4, 5) and contains many factors which contribute towards injury. This study examines only extrinsic factors (excluding wind gusts and dropping height) and takes no account of intrinsic factors such as weight, height or fatigue etc. Neither does it examine the association of the various extrinsic factors with seriousness of injury nor with how the injury was sustained.

The major finding is the association between injury rate and wind speed and wind direction; equipment;

night parachuting; and numbers exiting the aircraft. The association of injury with night and wind speed has been previously reported (6, 7, 8) although the magnitude of the increase injury rate with wind speed seems greater in this study. The association with numbers exiting, equipment and wind direction does not appear to have been previously demonstrated, although the Israeli (7) study does discuss equipment.

Equipment

The factor in the fitted model contributing most to the variation in rates was equipment. Certainly it is the view of many that average equipment weights have increased, even on non-exercise parachuting, with on exercise a greater proportion carrying the maximum permitted. It is thus impossible to adopt the previous practice of putting the man with the exceptional load close to the exit door as so many have an "exceptional" load. In any case with the longer Dropping Zones required to drop 90 men, the man with the heavy load is reluctant to have the advantage of being the first man out if he then has to walk the length of the DZ to join up with his company! Commanders too are keen to get their units together as quickly as possible, which requires individuals being sited in the aircraft at a position that will deliver them as close as possible to the rendezvous.

It is also worth noting that the all up weight of a parachutist and his equipment should not exceed 157.5 kgs (350 lbs), the limit for the parachute. The man with the maximum personal load of 53.1 kgs (118 lbs) of equipment will also have another 27 kg of parachute, reserve, life jacket and helmet, a total over 80 kgs. This leaves only 77.4 kgs for the man, his boots and his clothes. As 29% of the Parachute Regiment personnel exceed 77.4 kgs (data based on a concurrent study into the effect of intrinsic factors) some individuals may parachute above the maximum weight for the parachute, particularly as larger men always seem more suited to carrying the heavier loads. With 148.5 kilos the rate of descent (9) is 6.096 metres (20 ft) a second; this rate will increase with heavier loads. Unfortunately there was no data on equipment weights and a prospective study is required to assess its effect, particularly as it is considered that equipment weight may contribute to the variation associated with some of the other factors.

On operations there is little that can be done to minimize the effect of equipment weight; parachuting forces have learnt that the only equipment that can be guaranteed is that which is carried on the parachutist or pushed out by him. However if a casual association between equipment weight and injury rate is demonstrated then consideration will have to be given to reducing, during peace time training, the upper limit for equipment weight.

Wind Speed and Direction

The wind speed limits now applying to UK military

parachuting are in essence derived from the first UK survey of parachute injuries in 1942 at the inception of Airborne Forces (6). Both that study and the current one indicated that injury rates were about 1% until 9 knots; with increased wind speeds injury rates then rapidly increase. The current study though shows a rate increase of three and a half times between 9 and 13 knots compared to the two-fold increase of the 1942 study, in spite of the current parachute being much more stable in higher wind speeds than its 1942 predecessor. It is interesting to note Belgian (8) experience where the rise in injuries classified as moderate parallels the UK 1942 experience, but at a lower rate. For severe injury the rise in the Belgian rate commences at 13 knots (their upper limit being 16 knots). Thus in the current study, whilst an increase in injury rate with wind speed was expected, the rate of increase was a surprise. There is no clue in the data to explain this finding, although it is suspected that equipment weight may be the cause.

Another explanation is that wind measurements are not accurate, and it is the case that the DZ party are sometimes located below the highest point on the DZ. However the anemometers appear well maintained, are regularly recalibrated by the Meteorological Office, seem to be read with care and recordings do not indicate any particular bias, (eg even numbers) and accurate recordings are required for the aircraft to correctly estimate the release point for parachutists. Thus readings seem to be as accurate as the instrument and its location permit. It would, however, be worthwhile studying the variation of wind speed across Dropping Zones using one or more continuous reading recorder which can also measure gusts. What the current data suggests (and appears not to have been previously reported) is that wind speed needs to be considered in conjunction with wind direction. Currently wind direction is not taken into account in setting peace time restrictions.

A possible explanation for the effect of tail winds is that on exiting the aircraft the nature of the exit and the air-stream characteristics result in the majority of parachutists facing backwards (ie with his back to the departing aeroplane). With a tail wind this means the wind will be blowing him backwards and backward landings are traditionally associated with an increased injury rate (so called Ha-Ha landings: heels, arse, head, ambulance) and was the reason why UK parachutists used to be taught to rotate their canopy by crossing the lift webs (6). Current teaching is that the horizontal velocity should be reduced by pulling down on the parachute straps; this however increases vertical velocity.

Numbers Exiting

There do not appear to be any previous reports of an association of injury rate with numbers exiting (few nations drop in excess of 64 simultaneously from one

aircraft). Such an association should not surprise. A large number exiting will mean that the aircraft will have been crowded with resulting discomfort, longer standing time during final preparation, greater distances for some individuals to travel inside the aircraft (all leading to fatigue) and difficulty in maintaining the stagger (necessary to reduce mid air collisions) between those on the two sides of the aircraft. All these may lead to a greater probability of injury during or just after exiting and possibly slower reaction to emergencies in the air. It also seems that almost all programmes with large numbers exiting were major exercises. These will have had the additional stress of heavier equipment (which may be acting as a confounding factor), longer preparation time, possible delays for weather and a long low level flight which will all contribute to making the parachutist at less than peak condition when he leaves the aircraft.

Day and Night

The Israelis (7) report a significant increase in injury rate at night (to 2.43%). An increase was also found in the first UK (6) and the Belgian (8) study (though they rely on data mainly from Balloons). It was thus surprising to find such a small increase in the UK night injury rate (to 1.37%). In the current study it only becomes significant on logistic regression. It could be that the UK limit for night parachuting of 9 knots reduces the rate compared to other studies, or equipment weight at night was less, or the effect is hidden by an increased day time injury rate.

Dropping Zone

Five Airborne Brigade uses numerous Dropping Zones, none of which is prepared for parachuting. Those more commonly used are kept free of new forestry and buildings but generally the only criteria for a Dropping Zone is that it is free of major obstructions. It was thus surprising to see the lack of effect of adding DZs to the model and only four were significant. Of the two associated with a reduced injury rate one is criss-crossed with deep re-entrants and has a large number of small but significant obstructions. The other also has a large number of re-entrants. It might be that their topography reduces the effect of wind; it is a subject that bears investigation. Of the two DZs associated with a significantly increased rate, one, in Kenya, is at altitude. Together with the high temperature this reduces the capability of the parachute and, in spite of lower maximum equipment weights allowed, may have been responsible for the higher injury rates. The other, Feigheldean Down is not obviously exceptional. It only received 595 descents and the effect may be a statistical quirk.

UK Rates

The UK rate of 1.11% compares to worldwide reported injury rates which are generally below 1.0%, with recent United States (10), Belgian (8) and Israeli (7) in-

jury rates being lower at 0.06%, 0.50% and 0.625% respectively.

It is difficult to compare injury rates between nations. Definitions of injury differ as do the means of identifying them. There is likely to be a difference between the rate of casualties identified on the DZ (as in the UK) and those identified in the local hospital as was used by Petras et al (11) to report an injury rate in the US of 0.68%. Rates will differ due to the different proportions of aeroplane, free-fall and balloon descents. A high proportion of free-fall and balloon descents will reduce the overall rate and reports in the literature do not always indicate the mix. Rates also differ between those in training and trained parachutists. Thus the Belgian experience (8) of an injury rate of 0.5% in their Training Centre, with a much greater proportion of Balloon descents and descents without equipment, and onto one Dropping Zone cannot easily be compared with this study's rate.

One study that can be compared with the current one is the Israeli (7), which separately records basic training, exercise and refresher descents. The last two groups seem similar to those in this study and had an injury rate of 0.654% by day and 2.433% by night. Their rate is thus much lower by day and much higher by night, but there is no clue to why.

Looking at the various rates from other nations and the 1942 UK data it appears that the UK's rate is now higher, even after taking into account wind speed, day and night descents and mixture of aircraft. This leaves Dropping Zones, equipment or some other unidentified factor as the cause.

Implications for Peacetime Training

If the associations demonstrated in this study are confirmed and shown to be the cause of the increased injury rate, and once the effect of equipment weight is ascertained, a review of the limits for peace time training needs to be undertaken. There are two approaches to designing such limits.

The first is the imposition of strict limits separately for each of the parameters shown to cause an increased injury rate. This has the advantage of being simple, clear and unambiguous. However the design of such limits would not be easy as a judgement on the relative importance of the individual factors would first be required. For example wind speed limits could be set higher if the numbers exiting were limited to 64, but many may feel it is more important to be able to parachute with full aircraft, even if that meant accepting lower wind speed limits.

The second approach is thus preferred. A decision is made on what is an acceptable injury rate. Using Annex A (or a similar table) Commanders can then decide which combination suits their situation best. Different target injury rates can be set for training of differing importance, with "ordinary" continuation training

ANNEX A: PREDICTED INJURY RATES

For parameters:	No Eqpt	+ Day	+ Wind 9kts or less	+ Below 64 Exiting:	Injury Rate =	0.12%
For parameters:	No Eqpt	+ Day	+ Wind 9kts or less	+ Over 64 Exiting:	Injury Rate =	0.32%
For parameters:	No Eqpt	+ Day	+ Wind over 9kts, not Tail	+ Below 64 Exiting:	Injury Rate =	0.22%
For parameters:	No Eqpt	+ Day	+ Wind over 9kts, not Tail	+ Over 64 Exiting:	Injury Rate =	0.63%
For parameters:	No Eqpt	+ Day	+ Wind over 9kts, & Tail	+ Below 64 Exiting:	Injury Rate =	0.40%
For parameters:	No Eqpt	+ Day	+ Wind over 9kts, & Tail	+ Over 64 Exiting:	Injury Rate =	1.11%
For parameters:	No Eqpt	+ Night	+ Wind 9kts or less	+ Below 64 Exiting:	Injury Rate =	0.20%
For parameters*:	No Eqpt	+ Night	+ Wind 9kts or less	+ Over 64 Exiting:	Injury Rate =	0.56%
For parameters*:	No Eqpt	+ Night	+ Wind over 9kts, not Tail	+ Below 64 Exiting:	Injury Rate =	0.39%
For parameters*:	No Eqpt	+ Night	+ Wind over 9kts, not Tail	+ Over 64 Exiting:	Injury Rate =	1.09%
For parameters*:	No Eqpt	+ Night	+ Wind over 9kts, & Tail	+ Below 64 Exiting:	Injury Rate =	0.70%
For parameters*:	No Eqpt	+ Night	+ Wind over 9kts, & Tail	+ Over 64 Exiting:	Injury Rate =	1.93%
For parameters:	Equipment	+ Day	+ Wind 9kts or less	+ Below 64 Exiting:	Injury Rate =	0.82%
For parameters:	Equipment	+ Day	+ Wind 9kts or less	+ Over 64 Exiting:	Injury Rate =	2.25%
For parameters:	Equipment	+ Day	+ Wind over 9kts, not Tail	+ Below 64 Exiting:	Injury Rate =	1.58%
For parameters:	Equipment	+ Day	+ Wind over 9kts, not Tail	+ Over 64 Exiting:	Injury Rate =	4.30%
For parameters:	Equipment	+ Day	+ Wind over 9kts, & Tail	+ Below 64 Exiting:	Injury Rate =	2.79%
For parameters:	Equipment	+ Day	+ Wind over 9kts, & Tail	+ Over 64 Exiting:	Injury Rate =	7.45%
For parameters:	Equipment	+ Night	+ Wind 9kts or less	+ Below 64 Exiting:	Injury Rate =	1.42%
For parameters*:	Equipment	+ Night	+ Wind 9 kts or less	+ Over 64 Exiting:	Injury Rate =	3.87%
For parameters*:	Equipment	+ Night	+ Wind over 9kts, not Tail	+ Below 64 Exiting:	Injury Rate =	2.73%
For parameters*:	Equipment	+ Night	+ Wind over 9kts, not Tail	+ Over 64 Exiting:	Injury Rate =	7.28%
For parameters*:	Equipment	+ Night	+ Wind over 9kts, & Tail	+ Below 64 Exiting:	Injury Rate =	4.78%
For parameters*:	Equipment	+ Night	+ Wind over 9kts, & Tail	+ Over 64 Exiting:	Injury Rate =	12.33%

Notes

Tail Wind is a wind blowing the same direction that aircraft is flying, in the arc 120 degrees to 240 degrees.

Those marked with an * are extrapolations beyond the collected data and may thus not be a good guide to future rates.

Relative Risk:

Equipment	7.14	More than 64 exiting	2.80
Night	1.80	DZ Kenya	5.90
Wind more than 9kts, no tail	1.95	DZ Feigheledean Down	2.44
Wind more than 9kts, tail	3.49	DZ Imber	0.37
Relative risk for wind direction in winds > 9kts	1.79	DZ Breakheart Bottom	0.50

having a lower rate set that a major Brigade exercise. Such an approach will also allow the updating of the selected regression model and will emphasise to Commanders the human cost of their decisions. Its disadvantage is that it is more complicated and it may fall into disrepute as the rates in Annex A are mean expected rates and individual parachute programmes will sometimes depart considerably from that mean.

In either approach an "acceptable" injury rate has to be defined. This is largely a subjective decision, although a study of the outcome of the 379 casualties in this study might provide some objective assistance. It is noted that if the injury rates that led to the imposition, in wartime, of the 13 knot maximum wind speed in training were to be applied today the maximum wind speed permitted would be between 9 and 11 knots.

However it may be that equipment weight is potentiating the other factors, and if this is so the reduction in equipment weight would reduce the need to alter other limits.

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