Comparative analysis of 405 Central European ball lightning cases

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Abstract

Two Austrian BL data banks (ABLD 1 - 150 cases, and ABLD 2 - 103 cases) and a Central European BL data bank (CEBLD, 152 cases, mostly German) were analyzed and compared[1]. Data collection with witness contacts by the first author had used the same field investigation and questionnaire scheme since 1974, which means high documentary consistency.

The analysis found unexpectedly constant statistical patterns with regard to reporter populations, social witness reactions, time cycles and durations, meteorological conditions, distance, size, motion data and phenomenological details of BL (form, colour, surface, luminosity). The data were compared with the old European BL data bank of Brand (1923) and other sources. An extreme group test showed high stability of the patterns over time within the 20th century. The three data bank profiles indicate one time-constant, space-invariant set of BL phenomena all over Central Europe.

Introduction

In 27 years (1974-2000), the first author as meteorologist and psychologist has collected and investigated 650 ball lightning (BL) reports. Several outstanding cases have already been published (Keul, 1992, 1994, 1997, 1999a, 2000; Keul, Gugenbauer & Diendorfer, 1993). 150 Austrian BL cases were put in a first BL data bank called ABLD 1, statistically evaluated for ISBL 1 at Tokyo (Keul & Schwarzenbacher, 1988) and with the Russian Stakhanov-Grigoriev data bank (Bychkov, Smirnov & Stridjev, 1993). 134 more cases, 103 already coded, make up a second Austrian BL data bank called ABLD 2. From German-speaking witnesses around Austria, 152 BL cases have been collected and coded as data

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bank CEBLD. Cases with insufficient information, under investigation, not fully coded or outside Central Europe are not presented here.

The documented BL case density for Austria (8 million inhabitants, population density 95, 284 cases on file) of one case per 28.000 inhabitants is two times higher than for densely populated Japan (126 million inhabitants, population density 333, 2.060 cases according to Ohtsuki & Ofuruton, 1989) with one case per 61.000 inhabitants.

With the help of director Alfred Geiswinkler, state and industry research funds made it possible in 2000/2001 to code, statistically evaluate ABLD 2 and CEBLD, and match them with ABLD 1. Although the European data sets are smaller than the collection of Stakhanov/Grigoriev by the factor ten, they are very homogenous: 85% of the cases were documented systematically by the same questionnaire type following first reports. The two parallelAustrian data banks enable a split-half stability test.

Material and method

A series of calls for BL reports started 1974 in Austrian newspapers and magazines. Besides, several existing BL records at the Central Meteorological Station at Vienna were used, and a number of reports travelled through meteorological or astronomical channels. Most German reports were triggered by a 1981 BL article in the science magazine "Bild der Wissenschaft" and by extensive press coverage on the Salzburg BL congress Vizotum (Keul, 1993). Of 650 raw reports, 11% were eliminated as non-BL, 14% had insufficient data for coding, 2% were under investigation, 10% still uncoded and 1% outside Central Europe. 405 cases from Central Europe - 62% of the raw data - were coded/re-checked and evaluated in this research project.

Table 1. Descriptive statistics of the three Central European data banks

Variables	*Austria ABLD 1 (n = 150)*	*Austria ABLD 2 (n = 103)*	*mostly Germany CEBLD (n = 152)*
Location (Federal Province or country) *CEBLD: German-speaking population	25% Styria 21% Lower Austria 14% Vienna 13% Salzburg 11% Upper Austria 6% Vorarlberg 5% Carinthia 3% Tyrol 2% Burgenland	21% Lower Austria 18% Upper Austria 15% Styria 15% Salzburg 9% Vorarlberg 7% Vienna 6% Carinthia 5% Tyrol 4% Burgenland	16% Saxony 15% Bavaria 10% Baden-Württbg 8% Thuringia 7% Switzerland 6% Czechia* 6% Schleswig-Holst. 32% rest 1-4% each
Sex of witness	52% female 48% male	63% male 37% female	56% male 44% female
Witness age at observation	Mean 33,6 Range 5-83	Mean 32,7 Range 6-81	Mean 26,7 Range 4-82
Witness age at report	Mean 60,4 Range 16-91	Mean 67,9 Range 28-93	Mean 64,0 Range 23-93
Delta (time to report)	Mean 26,7 Range 0-78	Mean 35,3 Range 0-77	Mean 37,1 Range 0-81
Witness profession (at observation time)	26% employed 25% in training 10% academic 9% farmer, worker 9% housewife 9% self-employed 9% pensioner 3% pre-school	28% in training 22% employed 14% housewife 12% self-employed 8% pensioner 7% academic 3%: unempl./farmer 2% pre-school	50% in training 16% employed 10% housewife 6% academic 6% pensioner 5% farmer, worker 3%: self-em./pre-sch. 1% unemployed
Witness reaction	45% fascinated 35% frightened 15% calm 5% flight, panic 1% ambivalent	51% frightened 34% fascinated 11% calm 4% ambivalent no flight, panic	46% frightened 33% fascinated 15% calm 5% ambivalent 1% flight, panic
Number of persons	Mean 2,2 Mode 1 Range 1-8 Peaks: 1 49% 2 28%	Mean 2,1 Mode 1 Range 1-30 Peaks: 1 53% 2 39%	Mean 2,2 Mode 1 Range 1-35 Peaks: 1 53% 2 26%
Year [year range] All peaks >3% each	Range 1909-86 [78] Peaks 50,72,76,77	Range 1911-98 [88] Peaks 33,35,57	Range 1900-92 [93] Peaks 38,43,52,53,63
Month	Peaks: July 30% Aug 27% June 22% all cases summer 87%	Peaks: July 37% Aug 32% June 13% all cases summer 84%	Peaks: July 35% Aug 29% June 13% all cases summer 87%
Hour (Peaks >3%)	Peak 2:30-5:00 P.M.	Peak 2:30-5:00 P.M.	Peak 2:00-6:00 P.M.
Thunderstorm * damp, oppressive	72% simultaneously 10% after thunderst. 7% before thunderst. 6% no thunderstorm 5% thundery*	68% simultaneously 14% no thunderstorm 10% after thunderst. 7% thundery* 1% before thunderst.	64% simultaneously 15% thundery* 10% no thunderstorm 7% before thunderst. 4% after thunderst.
Precipitation	55% simultaneously 39% no precipitation 6% prec. after BL	56% simultaneously 25% no precipitation 16% prec. after BL 3% prec. before BL	56% simultaneously 24% no precipitation 14% prec. after BL 6% prec. before BL
Lightning flash	57% no lightning flash 22% simultaneously 17% lightn. before BL 4% lightn. after BL	35% lightn. before BL 33% no lightning 24% simultaneously 7% lightn. after BL	40% no lightning flash 34% lightn. before BL 24% simultaneously 2% lightn. after BL

Variables (continued)	*ABLD 1 (n = 150)*	*ABLD 2 (n = 103)*	*CEBLD (n = 152)*
Number of objects	Mean 1,3 [range 1-8] 92% 1 object 2% 2 objects 1% 3 objects	Mean 1,0 [range 1-2] 99% 1 object 1% 2 objects	Mean 1,1 [range 1-5] 94% 1 object 3% 2 objects 3% 3 objects
Duration	Mean 7,7 sec. Median 3, Mode 2 Range 1-180 sec.	Mean 28,2 sec. Median 5, Modes 2, 4 Range 1-900 sec.	Mean 15,4 sec. Median 5, Mode 5 Range 1-600 sec.
Shape	91% round 6% oval, elliptical 2% oblong 1% other, variable	88% round 6% other 4% oval, elliptical 2% oblong	96% round 2% variable 2% other 1% oblong
Distance object-observer	Median 5 m Range 0-8 km 50% < 5 m	Median 10 m Range 0-5 km 50% ≤ 6 m	Median 6 m Range 0-10 km 50% ≤ 5 m
Object size	Mean 30,1 cm Median 25, Mode 30 Range 1-150 cm	Mean 68,8 cm Median 30, Mode 30 Range 1-1.000 cm	Mean 41,6 cm Median 30, Mode 30 Range 1-500 cm
Object surface	74% sharply defined 18% fuzzy 7% core + halo 1% transparent	74% sharply defined 17% fuzzy 7% non homogenous 2% core + halo	77% sharply defined 10% fuzzy 7% core + halo 6% non homog. etc.
Colour	32% yellow 17% orange 14% white 11% red 8% blue-white 8% blue, violet 7% variable 3% green	29% yellow 24% orange 15% white, grey 12% fiery 9% red 6% green, variable 3% blue-white 2% blue, black	43% yellow 12% orange 10% white, grey 10% variable 10% fiery 8% red 5% green, blue, viol. 2% blue-white
Brightness	82% not blinding 15% blinding 3% flickering	68% not blinding 21% blinding 8% flickering 3% other	73% not blinding 21% blinding 4% flickering 2% other
Primary motion	50% horizontal 25% downwards 12% complex 11% stationary 1% upwards	46% horizontal 33% downwards 10% stationary 9% complex 2% upwards	53% horizontal 23% downwards 13% complex 10% stationary 1% upwards
Secondary motion	86% none 6% hopping 4% oscillating 2% circling 2% irregular, jerky	82% none 13% hopping 2% circling 2% irregular 1% oscillating	85% none 9% hopping 3% circling 2% irregular, jerky 1% oscillating
Other details Individual phenomena, no sum-up to 100%	35% inside buildings 14% smell 15% sound 14% sparks, 4% tail 22% residue 24% formation seen 80% end seen (38% explosive)	27% inside buildings 14% smell 14% sound 11% sparks, 9% tail 23% residue 23% formation seen 71% end seen (36% terminal bang)	33% inside buildings 11% smell 18% sound 9% sparks, 6% tail 26% residue 28% formation seen 76% end seen (53% terminal bang)
Investigation quality *contact first author-witness	73% quest/phone int* 11% field investig.* 11% written report 5% secondary rep.	78% phone interview* 11% questionnaire* 11% written report	89% questionnaire* 10% written report 1% scientific journ.

Most first contacts were written reports. All reporters were sent a standard questionnaire made up of 54 questions to be filled in and returned by the witness. Others were filled in by the first author during phone interviews. Field investigations used the same instrument. With only minor variations in the questionnaire over the years, 84-89% of the BL cases were documented in the same data format.

The coding scheme used 46 variables. 11 variables had absolute values, 5 were ordinals and 12 nominals. 18 other (nominal) phenomena were coded binary (existent/non-existent) and added as a data string. 150 cases of ABLD 1 had been coded by the first author and a colleague (1989), the 103 cases of ABLD 2 and the 152 cases of CEBLD were freshly coded by the second author and control-read by the first.

The 28 non-binary variables were transferred to a SPSS file for statistical analysis. After the descriptive statistics (see Table 1 for the main results), hypothesis-based correlations were computed.

Results and discussion

The results of three different BL data banks from Central Europe gave the opportunity for a statistical comparison of data collected in countries with a common language, and documented in a continuous format. Thus, major differences between ABLD 1, 2, and CEBLD should be due to variations in the BL phenomenon or reporting behavior in time and space. Comparing the three data banks, the following structures were noticed:

Location: The data are a *report* distribution, not a clear *occurrence* statistics of BL phenomena. Media calls-for-reports had certain social and age impacts. The *potential* for BL reports appears as a superposition of thunderstorm frequency and population density (Keul & Schwarzenbacher, 1989).

Reporter population/behavior: With the exception of ABLD 2, the witness ratio male:female was balanced. Long time-to-report deltas (27-34 years) occurred. All observer age distributions are skewed to the left, all reporter age distributions skewed to the right. This means that BL were more readily observed by young people active in open countryside, and reported by interested old newspaper readers who had time and motivation to write a message. The profession

statistics shows a high percentage of young people in training (school, apprenticeship, army) and of academics (a reporter self-selection effect).
35 to 50% became frightened by BL, 45 to 60% stayed calm or were fascinated. Only up to 5% showed flight and/or panic.
Every second case was a one-witness case. About 25 to 40% of the cases had two observers, 10 to 25% happened with more than two people.
Years: With ranges of 80 to over 90 years, all three data banks cover most of the 20th century. The peaks are different in the three data sets.
Month and time of day: Summer is European thunderstorm and BL season with a peak in July. The afternoon BL peak (Austria 2:30 – 5:00) overlaps with the local thunderstorm maximum.
Coincidence with thunderstorms/precipitation/lightning: With 60 to 70%, the thunderstorm connection is prominent. Precipitation, often strong, occurs simultaneously in over 50%. A cloud-to-ground flash precedes/goes with BL in 30-60% of the cases, according to the witness, i.e. with room for speculation.
Object number: With well over 90%, the typical case is a single object event. However, up to five or even eight objects may appear on rare occasions.
Duration: No BL cases were eliminated due to long durations reported. Anyway, 50% of the cases last less than 2 to 5 seconds. Medians and modes are all in the area of 2 to 5 seconds.
Shape: Around 90% (Austria) to 95% (Europe) of the objects are reportedly globular. In Austria, 6 to 8% other round shapes are seen, outside Austria less.
Distance: In 50% of all cases, the minimum distance observer-phenomenon was under 5 or 6 meters. This means descriptions of close-up phenomena. Objects are seen in open countryside to a maximum distance of 10 kilometers.
Object size: No BL cases were eliminated due to large sizes reported. The median and modal sizes lie between 25 and 30 centimeters. Very large objects are rare.
Surface/colour/brightness: Around 75% were sharply defined objects, 10 to 20% had fuzzy outlines, a small but consistent percentage a central core with halo. The main colour ranks were highly similar in all data banks: yellow-orange-white-fiery/red. 70-80% were non-blinding objects, i.e. easy to look at.
Motion: About 50% showed horizontal motion, 20-30% moved downwards. A steady proportion of 20-25% in all data sets moved erratically or not at all.

Around 85% had no secondary motion pattern. The rest showed consistent secondary patterns described as circling, bouncing, oscillations or jerks.
Other details: Every third BL phenomenon happened inside a building. The percentages for smell, sound, and sparks are very similar. Every fourth report includes residue – big damage is rare. In about 25% of the cases, BL formation was seen, and in 70-80%, the final stage was seen (40-50% being explosive).
Investigation quality: 84-89% of the data bank cases had been investigated in direct interaction of the first author and the witness (field trip, phone, by mail), the rest of 14-16% consists of "handwritten" (10%) or secondary reports with sufficient details given.

Austrian split-half statistics (ABLD 1 and 2)
To perform a split-half test, Austrian cases forthcoming after 1988 were put into a second data bank. Looking at the main witness, object and location variables in Table 1, the data sets are remarkably similar except for some differences: Locations differ after the first author had moved from Vienna to Salzburg in 1980. ABLD 1 data were collected until 1988, thus stop with observation year 1986, ABLD 2 data - collected later on - with year 1998. The reported occurrence of lightning flashes is different for ABLD 1 and 2, but similar between ABLD 1 and CEBLD. Reported durations range much higher in ABLD 2, also in CEBLD. The same effect is noticeable for object sizes.

Table 2. Comparison with four BL data banks

Variable	*ABLD 1*	*ABLD 2*	*CEBLD*	*Brand, Egely, Russia, USA*
Month	max 30%July	37%July	35%July	max July: 23%(B,E), 39%(R)
Hour (PM)	2:30-5:00	2:30-5:00	2:00-6:00	4:00-6:00 (B), 12:00-3:00 (R)
Thunderstorm	72%simult	68%simult	64%simult	>50% (B)
Lightning	57% none 22%simult	33% none 24%simult	40% none 24%simult	K=0,8 (R), 85% (U)
Duration (sec)	50% <3	50% <5	50% <5	>50% 1-5 (B), 43% 1-5 (E), 10±3 (R), 61% 1-4 (U)
Distance (m)	50% <5	50% <6	50% ≤ 5	49% 1-5 (E), 33% 1-5 (R)
Size (cm)	50%<25	50%<30	50%<30	10-20 (B), 23% 20-30 (E), 64% 10-50 (R), 55% 13-40 (U)
Colour	49% yellow- orange, 11%r	53% y-o, 9% red	55% y-o, 8% r	26% y-o, 43% r (B), 24% y-o, 27% r (E), 35% y.o, 19% r (R),
Explosion	31%	26%	38%	29% (B), >50% (R)

Comparison with four published BL data banks

Stenhoff (1999, 12) recently listed up nine national BL data sets with 5.700 reports. Details of an early Central European archive (n = 215, Brand, 1923), US survey data (n = 513, Dewey, 1954), the Russian Stakhanov-Grigoriev data bank (n = 2.500, Smirnov, 1993; Bychkov, Smirnov & Stridjev, 1993) and a Hungarian collection (n = 278, Egely, 1987) were accessible to the authors.

Table 2 gives a phenomenological data comparison of the three data sets evaluated above with the four sources listed. It is apparent that the case distribution by month has a uniform maximum in July. The diurnal case maximum is earlier with Brand and later in Russia. Brand lists over 50% heavy thunderstorms associated with his cases. The US lightning connection is much stronger than in Central Europe. Smirnov computed a correlation coefficient of 0,8. The duration data show a high consistency in the region of 1 to 5 seconds. Smirnov gets a lifetime of 10 ± 3 seconds. The distance data in Hungaria are similar with every second case under 5 meters, in Russia every third case. All size curves peak in the area under 50 centimeters with a maximum region between 10 and 30 centimeters. The three Central European data banks presented here have every second object in the yellow-orange colour range. Other data banks contain less (24-35%) objects in this range, but more objects described as red (except Russia). Nevertheless, the yellow-orange-red sector is most dominant. The old Brand data collection records a similar frequency of exploding objects; the percentage is even higher in Russia.

Hypothesis testing by nonparametric correlations

Systematic testing as in an experimental design is not encouraged by the relative paucity of absolute-scaled data (11 variables) compared to ordinal (5) and nominal/binary data (30 variables). Kolmogorov-Smirnov tests done in SPSS with all three data banks indicated that only the witness age and report year data did not deviate significantly from a normal distribution. Therefore, nonparametric tests were run in SPSS:

Searching hypothesis-bound for a possible dependency of (subjectively reported) physical data and psychosocial data, three strong correlations were detected and tested with Kendall’s tau and Spearman’s rho.

Table 3. Significant and stable non-parametric correlations found

Phenomenon	*Data bank*	*Kendall's tau τ*	*Spearman's rho ρ*	*Significance level*
Sex - reaction	ABLD 1	τ -,252 p<,006	ρ -,268 p<,005	**
	ABLD 2	τ -,164 p<,093	ρ -,172 p<,095	n.s.
	CEBLD	τ -,211 p<,009	ρ -,224 p<,008	**
Reaction -	ABLD 1	τ -,308 p<,000	ρ -,374 p<,000	***
distance	ABLD 2	τ -,317 p<,000	ρ -,404 p<,000	***
	CEBLD	τ -,358 p<,000	ρ -,450 p<,000	***
Distance - size	ABLD 1	τ ,323 p<,000	ρ ,421 p<,000	***
	ABLD 2	τ ,247 p<,002	ρ ,334 p<,000	***
	CEBLD	τ ,283 p<,000	ρ ,383 p<,000	***

Table 3 gives the details on stable relations, i.e. occurring in all three data banks: A significant (**) correlation witness sex - witness reaction in ABLD 1 and CEBLD means that women either displayed or reported more fright than men. ABLD 2 contains only 37% female observers, ABLD 1 and CEBLD each over 50%. Short distances observer-object have a highly significant (***) correlation with fear reactions in all three data banks. This makes sense from a psychological point of view. A highly positive correlation (***) distance - object size means that objects further away are only seen when they are considerably bigger than BL seen nearby. Aerial perspective takes its toll.

Further results not shown in Table 3 are: Observation age is not related to object size or duration in all three data banks. The same is true for witness sex and object size/duration. A significant (p<,003) correlation between observation age and witness reaction in ABLD 1 does not hold for ABLD 2 or CEBLD. A significant (p<,010) correlation for number of persons and witness reactions only appeared in CEBLD, not in the Austrian data banks. Witness reaction and object size is not related in all three data sets. Witness reaction and object duration is significantly correlated (p<0,15) in CEBLD, but not in Austrian cases. Object size and object duration is not related in all three data collections.

Stability test of the patterns over time

Are the reported BL patterns stable over the decades of the 20th century? ABLD 1 and 2 cover the century from 1900 to 1998. Two extreme groups - 1900-1935 and 1970-1990 - were extracted from the data sets and analyzed.

The results are shown in Table 4. Month data were mostly missing for the old report group. The distance observer-object was twice bigger for the old case group. However, a good match indicating stability of patterns was obtained for time of day, duration and size.

Table 4. Stability of reported BL patterns from Austria

Variable	*1900-1935 (n=23)*	*1970-1990 (n=50)*
Month	3x July, rest: missing data	30% August, 27% July, 24% June
Time of day	Peak 2:30 - 3 P.M. (25%)	Peak 2:30 - 4 P.M. (26%)
Object distance	Median 12,5 m; 50%<10 m	Median 5 m; 55%<5 m
Duration	Median 3 sec; 81%<5 sec.	Median 3 sec; 77%<5 sec.
Size	Median 30 cm; 47%<25 cm	Median 30 cm; 49%<25 cm

Conclusion

The statistical analysis of three Central European data banks found *unexpectedly constant patterns across the files* with regard to reporter populations, social witness reactions, time cycles and durations, meteorological conditions, distance, size, motion data and phenomenological details of BL (form, colour, surface, luminosity). The main examples: Percentages of fear/no fear reactions are nearly identical. Time-of-year (July) and daytime (2-5 P.M. CET) is similar. 70% are thunderstorm-, 50% rainshower-, 25% cloud-ground-flash-related. Median durations are 3-5 seconds, median sizes 25-30 centimeters, 50% of the distances fall below 5 meters. 75% show a sharp outline, all colour rankings start with yellow, orange, white, 70-80% have non-blinding brightness. Comparisons with the old Central European data bank by Brand and other archives put the new Central European data statistically into the mainstream.

Summing up the results, the three data profiles obtained suggest one *time-constant, space-invariant* set of BL phenomena all over Central Europe.

Further evaluations of the three data banks are to follow. Recently, the growth of high-precision electronic lightning detection networks in Europe enables detection checks for lightning strokes associated with BL reports (Keul, 1999b). Innovation has also changed BL reporting. Now, first reports are often send as e-mails via internet. The first author offers a BL homepage and can be reached under alexander.keul@sbg.ac.at

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