ISSN 2079-0570, Advances in Gerontology, 2017, Vol. 7, No. 4, pp. 259–266. © Pleiades Publishing, Ltd., 2017.
Original Russian Text © I.B. Bychkovskaya, S.V. Mylnikov, T.I. Oparina, 2017, published in Uspekhi Gerontologii, 2017, Vol. 30, No. 3, pp. 323–331.

# On the Discontinuity of Annuity Curves in *Drosophila melanogaster* Wild Type Strain Canton-S. IV. The Effect of Rearing at Low Temperature during the Early Imaginal Stage

**I. B. Bychkovskaya[a], *, S. V. Mylnikov[b], and T. I. Oparina[c]**

[a] *Nikiforov Center of Emergency and Radiation Medicine of the Russian Ministry of Emergency Control, St. Petersburg, 194044 Russia*

[b] *Saint-Petersburg State University, St. Petersburg, 199034 Russia*

[c] *Ott Institute of Obstetrics and Gynecology, St. Petersburg, 199034 Russia*

**e-mail: i.b.bychkovskaya@gmail.com*

**Abstract**—The rearing of *Drosophila* fruit flies at a temperature 5–7°C lower than the standard level until day 13 (or day 22) of the imaginal period enabled an increase of the individual insect lifespan. The positive effect of the longest exposure was evident in all age groups. This effect was due to prolongation of the initial period of the individuals' lives and the subsequent delay of the onset of later developmental stages. The observed phenomenon may result in delayed development of aging-related pathology and a significant increase in the object's maximal lifespan. The effect was independent of sample size (in samples of 100 to 1200 flies) and the interval between the experiments. All individuals of the cohort are assumed to contribute to the phenomenon.

*Keywords: Drosophila*, annuity curves, discontinuous character, variance, decreased temperature, initial period, lifespan

**DOI:** 10.1134/S2079057017040038

## INTRODUCTION

Our earlier studies yielded experimental data on the highly discontinuous five-phase structure of *Drosophila* annuity curves and on the existence of two forms of individual lifespan variability (ILV) [4, 5, 8].

The first form (ILV1), which was demonstrated by numerous serial observations, manifested as systematic (intertrial) unpredictable changes of phase duration correlated with the area under the curve and individual viability [4, 5, 8].

The second form of lifespan variability (ILV2) was secondary to ILV1. It consisted in annuity variance for relatively small cohorts. The variance did not have a significant effect on phase duration. The maximal variance value did not change between the experiments [4, 5].

In contrast to ILV1, ILV2 can be detected in a single replicate already, and this is important from the methodological point of view.

As we stated in our previous studies, the five-phase character of *Drosophila* annuity curves can be due to sequential aging-related degradation of at least two biological systems that formed in the course of evolution and are characterized by different levels of vulnerability to aging [5].

Spontaneous aging supposedly starts with defect accumulation in each of the key systems and continues as pronounced tissue depopulation and massive death of individuals (as a transition from quantity to quality), as in aging induced by irradiation [3]. In any case, the complex structure of *Drosophila* annuity curves calls for adequate assessment of geroprotective treatment efficiency, and the need for such an assessment indicates the essential character of "phase-wise" studies.

Rearing of the organisms at a lower temperature throughout the initial developmental stage was used as geroprotective treatment in the present study. The beneficial effect of a lower temperature was demonstrated in several research objects of various organization levels, including *Drosophila* [9], but the "cold exposure" was used throughout the cohorts' life. The effects of the agent applied during a single phase were not studied earlier, and therefore this phenomenon was addressed in the present study.

## MATERIALS AND METHODS

Wild-type *Drosophila* strain (Canton-S) were used as study objects. The flies were reared on a standard medium that contained sugar, yeast, semolina, and raisins. The virgin flies that hatched during a 24-hour period were collected and moved to new test tubes,

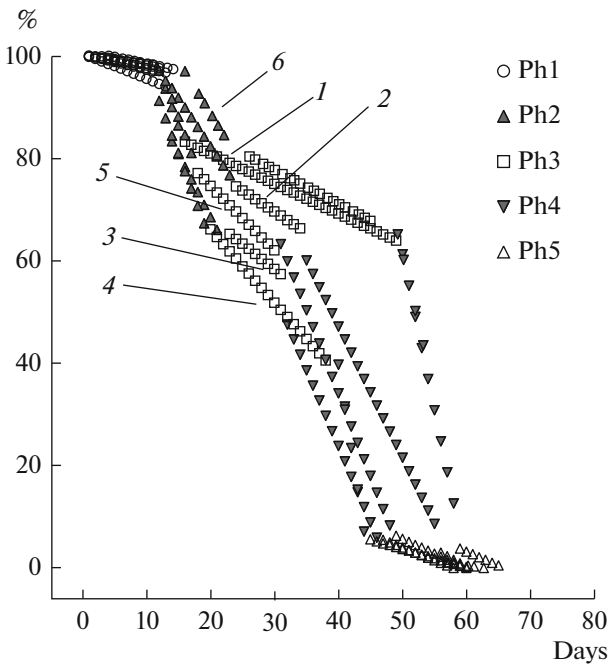


**Fig. 1.** Linear approximation of *Drosophila* annuity curves in six consecutive experiments performed under warm conditions; cohort size in the experiments: first—800, second—800, third—1200, fourth—800, fifth—400, and sixth—500 individuals. See text for a description of individual curve fragments (phases) shown in Figs. 1, 2, and 3.

where males and females were housed separately for 2 days. Egg clutches were collected from these parents in 1-day intervals. The flies that hatched within 1 day were placed into test tubes 1 cm in diameter with an agar-sugar nutrient medium covered by a freshly prepared suspension of yeast in distilled water. Ten male flies were placed into each test tube, and this allowed for parallel observations on the viability of cohorts of varying size.

The nutrient medium was replaced once a week. Annuity curves were constructed after the death of the last individual in the cohort.

The insects were maintained in stock cultures between the experiments. Flies were reared at either 25°C or a reduced temperature of 18 to 20°C ("warm" or "cold" conditions, respectively). The flies were 13 or 22 days old when the exposure to a lower temperature was stopped.

The major results of the experiments performed under warm conditions are reported in [4, 5, 8]. The number of fly generations monitored in these experiments was approximately 60 (if the time from zygote formation to sexual maturity is taken as one generation).

Four experiments that involved cold exposure ($1t°$, $2t°$, $3t°$, and $4t°$) were performed. The maximal interval between the experiments was 18 months, and approximately 36 generations passed during this time. The flies used in the experiment $1t°$ were either reared at a low temperature until the age of 13 days (experimental group) or reared at 25°C for the entire life (control). Experiment $2t°$ involved the comparison of data obtained from flies reared at a low temperature until 22 days of age to the results of six consecutive experiments performed previously at the conventional rearing temperature. Experiments $3t°$ and $4t°$ involved parallel monitoring of flies reared at a low temperature until the age of 13 or 22 days ("short" and "long" exposure to cold). Fly viability at different life stages (phases) was inferred from the area under the curve for the respective annuity curve fragments [4, 5].

Regression analysis (linear approximation) of the annuity curves [11] was performed. A novel approach consisting of the division of large cohorts into relatively small cohorts was used for variance assessment [4, 5]. The "small" cohorts used in the present study always consisted of 100 individuals. The terms "integrated" and "individual" were used to denote the respective cohorts and annuity curves.

The approach mentioned above allows for comparison of the character of fly viability variance and yields point and interval estimates of this parameter and the area under the different annuity curve fragments.

Linear regression analysis was used to assess the confidence intervals for the slopes of annuity curve fragments [11].

## RESULTS AND DISCUSSION

The results of linear approximation of *Drosophila* annuity curves for wild-type flies (Canton-S) are shown in Fig. 1. The results were obtained in a series of six experiments. Five discrete fragments (phases) with different slopes ("gently sloping" and "steep" phases) are apparent, and steep phases always follow gently sloping ones, with the exception of the terminal phase. The interphase transitions are abrupt. The slope values for gently sloping phases are always dramatically different from those for the steep phases. However, the curve slopes for each individual phase change only slightly between experiments.

Phase linearity, leap-wise alternation of slope angles, and the stability of slope angles for each phase are immanent features of the five-phase structure of *Drosophila* annuity curves [4, 5, 8].

Discrete curve fragments (phases) were assigned the following identifiers: Ph1, for the initial gently sloping phase of a very slow death rate increase; Ph2, for the steep transitional phase of intensive cohort demise; Ph3, for the gently sloping phase of a relative decrease of aging-related death rate; Ph4, for the steep phase of a rapid death rate increase in the cohorts; and Ph5, for the final gently sloping phase of a short-term death rate decrease.

ILV1, the second substantial characteristic of *Drosophila* annuity curves, is also illustrated by the data in

Fig. 1. A systematic change of phase duration between the different experiments is evident from the results of six consecutive experiments, along with the high stability of the "five-phase" pattern. Significant changes in the values of area under the specific curve fragments ("phases") correspond to the phenomenon and reflect the variability of individual fly lifespan [4, 5].

The following regularities are observed: longer gently-sloping phases (Ph1, Ph3, and Ph5) with lower slope angles correspond to larger areas under the respective curve fragments and a higher individual viability of the flies during the respective periods.

The presence of two components, a stable one (five-phase pattern) and a plastic one (phase duration variability), was a reproducible characteristic of the curves: as mentioned above, this curve type was observed over 2.5 years, which is equivalent to approximately 60 generations of flies. Therefore, this curve structure was regarded as genetically determined [5].

An attempt to prolong the gently sloping phases by exposure to a lower temperature was of interest for the present study, since this would reveal the efficiency of the modifier proposed. The initial gently sloping phase (Ph1) was selected in the present study. Two variants of exposure, a relatively short one restricted to Ph1 and a longer one that also included Ph2, were used in view of the assumption of two-phase deterioration of the key systems (see Introduction).

The data on the duration of the initial gently sloping phase of *Drosophila* annuity curves in experiments performed under warm and cold conditions are presented in Table 1.

The duration of the initial phase of annuity curves (marked as Ph1 according to the results of the experiments performed under warm conditions) apparently increased in all experiments that involved cold exposure (relatively to the normal conditions).

The extension of the Ph1 period is evident from the data on mortality dynamics in the warm and cold cohorts illustrated by Fig. 2 and Table 1. These changes reflect the increase in individual viability at the early life stage. Importantly, the positive effect of the agent does not subside after this stage. For instance, the effect of the relatively long treatment (Figs. 2b and 2d) was observed at virtually all stages of life. The effect observed was also evident during the terminal period, and an increase of the maximal *Drosophila* lifespan therefore appears possible.

Interestingly, some indirect pathways that provided for the positive effect existed along with the direct action of the treatment (dashed areas). These pathways are manifested as two different phenomena: (1) elongation of the initial fragment of the curves that extends beyond the zone of direct action (this reflects enhancement of the positive effect of treatment on *Drosophila* viability at an early age) and (2) delayed onset of subsequent aging-related demise. The characteristics of the effect observed did not depend on cohort size (100 to 1200 flies), which is indicative of the involvement of all insects in the reaction.

**Table 1.** Duration of the initial gently sloping Ph1 phase on the annuity curves from six consecutive experiments under warm conditions and four cold exposure experiments

| Experiment no. | Ph1 duration, days | Integrated cohort size |
|---|---|---|
| Experiments under warm conditions | | |
| 1 | 11 | 800 |
| 2 | 12 | 800 |
| 3 | 11 | 1200 |
| 4 | 9 | 800 |
| 5 | 11 | 400 |
| 6 | 15 | 500 |
| Experiments under cold conditions | | |
| Short exposure | | |
| $1t^{\circ}$ | 20 | 100 |
| $3t^{\circ}$ | 18 | 400 |
| Prolonged exposure | | |
| $2t^{\circ}$ | 39 | 1200 |
| $4t^{\circ}$ | 21 | 400 |

Analysis of the graphs revealed the absence of apparent differences between the overall directionality of curves from experiments under cold and warm conditions after the completion of Ph1. The dynamics of *Drosophila* demise became almost similar. The data presented above led to the assumption of a special significance of the initial period of *Drosophila* life for the course of subsequent life stages.

Let us use this assumption in the analysis of materials obtained from comparative analysis of fly viability variance under warm and cold rearing conditions that underlies the second form of fly lifespan variability (ILV2) [5].

Our previous studies [4, 5] indicated the nonuniform character of *Drosophila* viability variance during different life phases in the case of rearing under warm conditions. High stability of the maximal variance level was revealed as well; this parameter did not change between experiments [5]. The detection of nonuniform character of annuity curve variability at different phases allowed for a more complete and much less laborious analysis of annuity curve discontinuity. As mentioned above, the relatively large integrated cohorts were divided into smaller individual cohorts for variance assessment.

Let us compare *Drosophila* viability variance in experiments performed under warm (no. 3) and cold ($2t^{\circ}$) conditions with groups of insects of the same size (1200 individuals). The integrated cohort was divided into 12 parts in both experiments, so that individual cohorts of 100 flies were obtained. The integrated

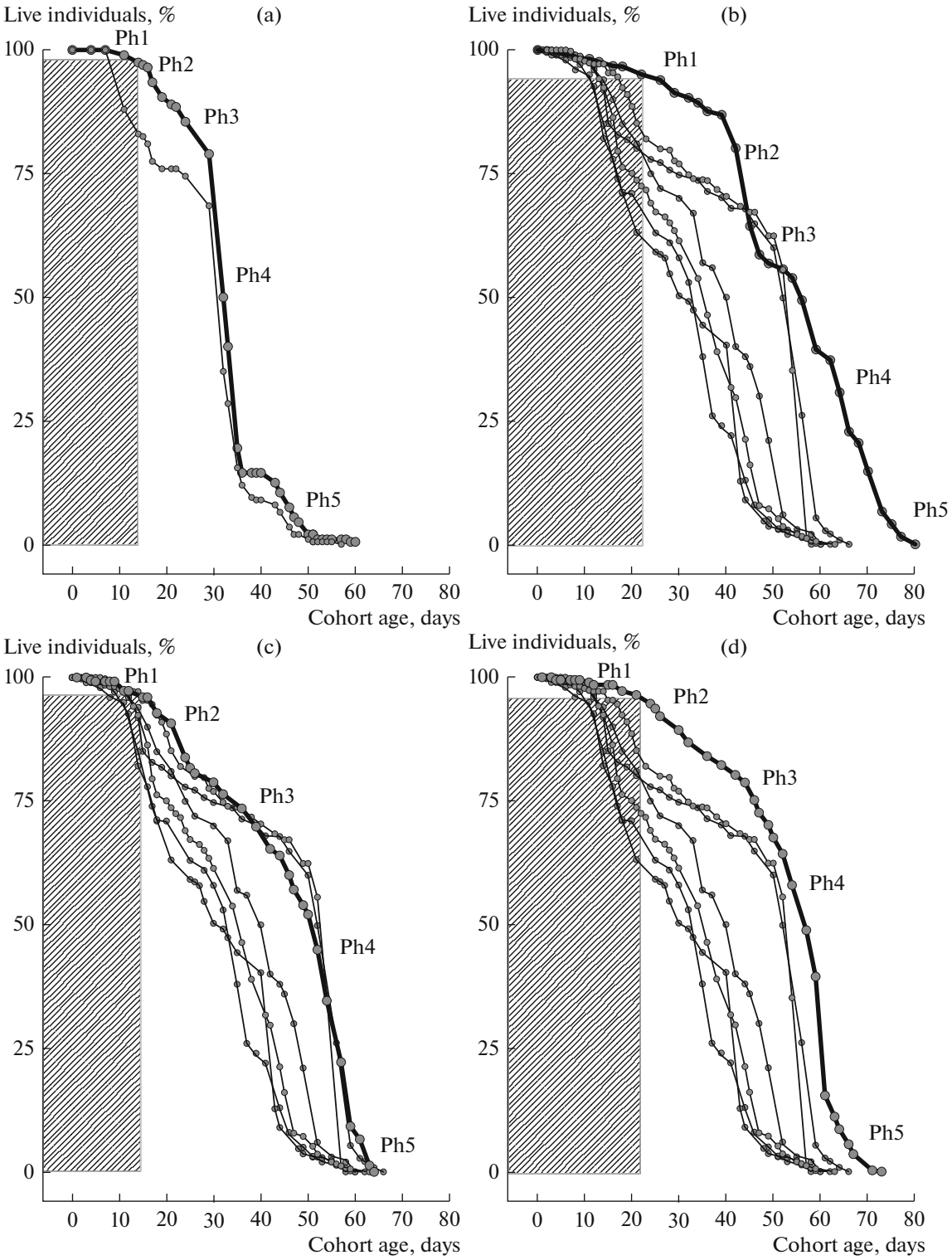


**Fig. 2.** Aging-related dynamics of annuity curves of fruit flies reared under normal conditions and exposed to a low temperature. (a) First experiment (1*t*°); (b) second experiment (2*t*°); (c) third experiment (3*t*°); (d) fourth experiment (4*t*°). Cohort size, individuals: experiment 1*t*°, 100, experiment 2*t*°, 1200, experiment 3*t*°, 400, and experiment 4*t*°, 400; the dashed area shows the cold exposure period.

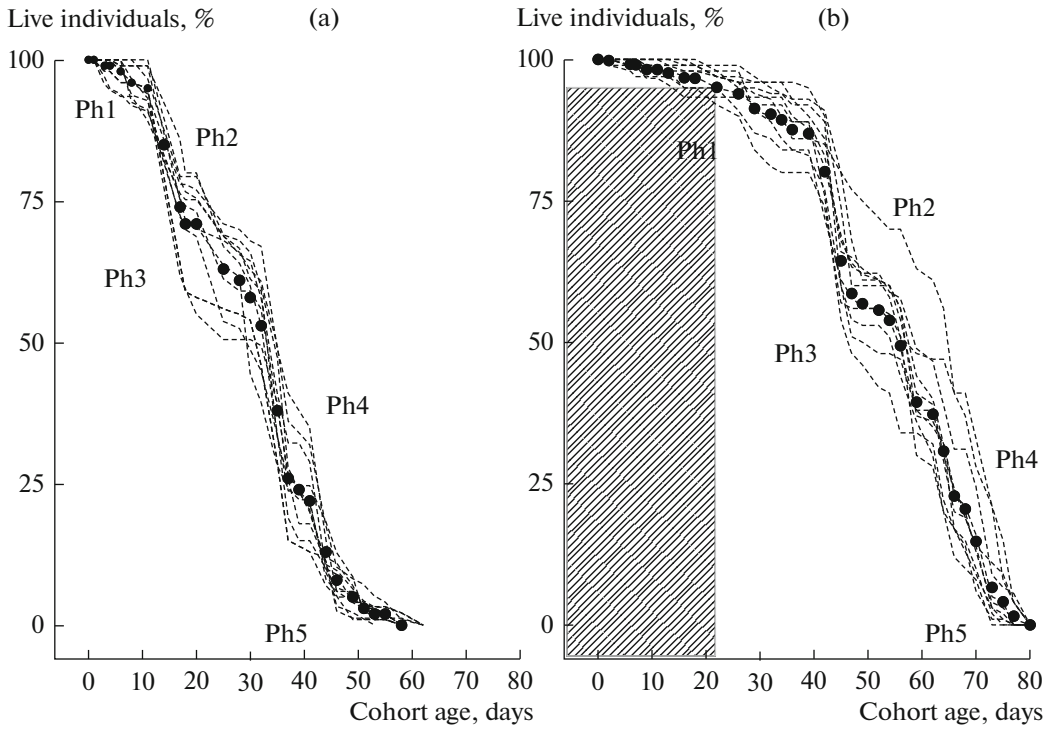


**Fig. 3.** Annuity curves for integrated (solid line) and individual (dashed line) cohorts in experiments performed under warm (a) and cold (b) conditions. The integrated cohort size is 1200 flies, and the individual cohort size is 100 flies. The dashed area shows the cold exposure period.

curve was regarded as the averaged curve on each individual fragment, and the sum of squared deviations of the relative number of live individuals in the individual cohorts was calculated for each fragment of the integrated curve. Let us first consider the experiment performed under warm conditions (Fig. 3a). The characteristic distribution of variance ranges that follows the phase pattern is apparent [5]. As is evident from the graph, the variance increases during the initial phase (Ph1) and the steep transition phase (Ph2), reaches a maximum and stabilizes during the relatively gently sloping phase Ph3, and decreases during Ph4 and Ph5.

Earlier studies demonstrated that the same variance pattern was preserved in each of six independent experiments performed over a time interval of 2.5 years. The described pattern did not change as the sizes of integrated cohorts were reduced from 1200 to 400 flies and remained the same as the sizes of the individual cohorts were reduced to 50 insects [5].

Let us now consider the results of the experiment that involved cold exposure (Fig. 3b). The five-phase character of *Drosophila* annuity curves and all of the distinctive features described above are apparently conserved after exposure to a low temperature. In this case we observe a similar increase of variance during Ph1 and Ph2, stabilization and the attainment of maximal values during Ph3, and a decrease during Ph4 and Ph5.

However, a dramatic extension of Ph1, the initial period, was observed in the cold-exposure experiment, as compared to the experiment at normal temperature. A positive effect was registered during the monitoring of each of the 12 individual curves. Accordingly, the area under the curve fragments Ph1 and Ph2 increased for both the "total" curve and all individual curves (relative to the experiment under warm conditions), which is indicative of a pronounced increase in fly viability at the early stage of life.

The character of variance for the cold exposure experiment did not differ significantly from that for the experiment performed at a normal temperature after Ph1 was completed. The characteristic pattern of variance distribution over the different phases described above was apparent. There were no apparent changes in the overall course of the individual curves.

A strong shift of both the integrated curve and all individual curves towards the later stages of life occurred. This is indicative of a delayed onset of the subsequent life stages (Ph2–Ph5) and an increased maximal lifespan of the cohorts. This delay is due to the prolongation of Ph1.

Importantly, the effect described above could already be detected reliably in a single cold-exposure experiment. As follows from [4, 5], a similar variance pattern was observed when experiment $2t^{\circ}$ was com-

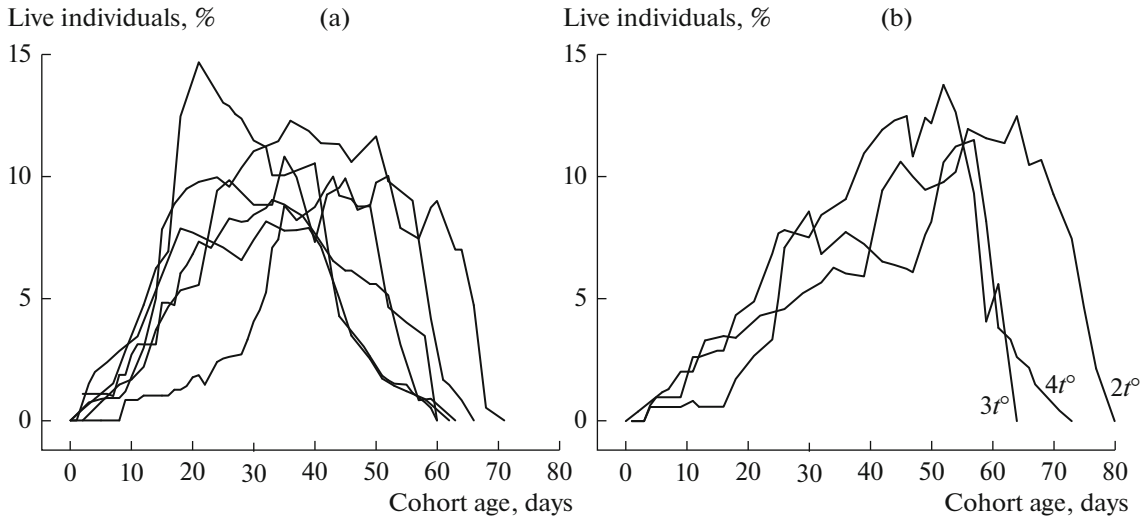


**Fig. 4.** Age-related dynamics of standard deviation of *Drosophila* viability. (a) Experiments performed under warm conditions, (b) experiments performed under cold conditions.

pared to any other experiments performed under warm conditions.

The presented data support the assumption (based on Fig. 2) of the leading role of the initial phase in the geroprotective effect addressed in the present study.

Further analysis involved the comparison of age-related dynamics of the standard deviation of *Drosophila* viability in experiments performed under cold and warm conditions. The analysis was performed for six experiments of the latter type and three cold-exposure experiments: $2t°$, $3t°$, and $4t°$ (experiment $1t°$ was not taken into consideration because the size of the integrated cohort was too small).

As is apparent from Fig. 4, the variance changes in the cold exposure experiments still followed the phase-wise pattern described above when this analytical approach was used. Significant extension of the initial phase (Ph1) relative to the value for flies reared at a normal temperature was observed in all experiments. The extension of this phase was apparently the key reason for the shift of the curves to later ages. This shift is especially distinct in the case of the variance level maximum observed during Ph3.

The results of quantitative assessment of the experimental material are given in Tables 2 and 3.

As can be seen from the data in Table 2, a significant increase of the area under the annuity curves in all cold exposure experiments (relative to the curves recorded at a normal temperature) and the related increase of individual object lifespan occurred during the initial stage of life (Ph1) only.

The data presented in Table 3 demonstrate abrupt slope angle alternations upon transitions from phase to phase in all cold exposure experiments (as in the experiments performed at a normal temperature). These alternations, along with the similarity of slope angles for each phase, are characteristic of the five-phase structure of object annuity curves [4, 5, 8]. Thus, the quantitative characteristics of slope angles of each phase fragment in the cold exposure experiments did not differ significantly from those for the experiments performed under warm conditions. Therefore, annuity curve slopes cannot result in the extension of the individual *Drosophila* lifespan reported in the present study.

The entire body of obtained data indicates the leading (key) role of the initial phase Ph1 in the manifestation of the geroprotective effect discovered. The positive effect is due to the extension of this phase and the delayed onset of the subsequent life stages (Ph2–Ph5). The delay of Ph2 occurred first. We believe that Ph2 reflects the second stage of damage to the system responsible for the early death of flies (see above). This phase does not begin before the end of the extended starting period (Ph1).

Phases Ph3, Ph4, and Ph5, which follow the second phase, are delayed as well, although they are apparently related to other biological mechanisms (other systems?). However, the onset order for Ph2–Ph5 is not affected. The life stages listed are just postponed. They follow each other according to the normal aging pattern in a manner similar to the movement of train carriages.

Importantly, the pattern described depended neither on statistical sample size (100 to 1200 flies) nor on the interval between the experiments (the maximal interval was 18 months and corresponded to approximately 36 generations). This is indicative of the total involvement of the flies in the processes under consideration and allows for the assumption of a genetically determined character of the "aging stage delay" phe-

**Table 2.** Area under the distinct fragments (phases) on the integrated annuity curve of fruit flies reared under normal conditions and exposed to a low temperature

| Experiment no. | Phases | | | | |
|---|---|---|---|---|---|
| | Ph1 | Ph2 | Ph3 | Ph4 | Ph5 |
| Experiments under warm conditions | | | | | |
| 1 | $_{790}795_{799}$ | $_{265}277_{288}$ | $_{1896}2152_{2407}$ | $_{257}309_{362}$ | $_{3}6_{9}$ |
| 2 | $_{1179}1188_{1196}$ | $_{581}609_{636}$ | $_{569}638_{706}$ | $_{502}592_{683}$ | $_{14}24_{47}$ |
| 3 | $_{1063}1075_{1087}$ | $_{200}214_{229}$ | $_{284}305_{326}$ | $_{318}368_{417}$ | $_{14}21_{28}$ |
| 4 | $_{883}891_{899}$ | $_{452}484_{517}$ | $_{627}762_{898}$ | $_{70}90_{111}$ | $_{14}27_{40}$ |
| 5 | $_{972}991_{1010}$ | $_{293}353_{413}$ | $_{584}835_{1086}$ | $_{256}471_{685}$ | $_{11}57_{124}$ |
| 6 | $_{1266}1286_{1306}$ | $_{578}629_{680}$ | $_{1284}1474_{1664}$ | $_{248}273_{299}$ | $_{0}3_{7}$ |
| Experiments under cold conditions | | | | | |
| Short exposure | | | | | |
| $3t^{\circ}$ | $_{1621}1664_{1707}$* | $_{374}425_{477}$ | $_{689}872_{1055}$ | $_{360}606_{852}$ | $_{0.06}24_{47}$ |
| Prolonged exposure | | | | | |
| $2t^{\circ}$ | $_{3620}3702_{3785}$* | $_{309}340_{371}$ | $_{247}278_{309}$ | $_{370}481_{591}$ | $_{2}8_{14}$ |
| $4t^{\circ}$ | $_{1954}1975_{1995}$* | $_{171}187_{204}$ | $_{1012}1170_{1328}$ | $_{667}880_{1093}$ | $_{4}12_{21}$ |

* Differ from all experiments performed under warm conditions; 95% CI is shown for all parameters here and in Table 3.

**Table 3.** Phase slope angles on the total *Drosophila* annuity curve under normal conditions and after exposure to a low temperature

| Experiment no. | Phases | | | | |
|---|---|---|---|---|---|
| | Ph1 | Ph2 | Ph3 | Ph4 | Ph5 |
| Experiments under warm conditions | | | | | |
| 1 | $_{-0.22}-0.2_{-0.08}$ | $_{-17.53}-3.6_{10.37}$ | $_{-0.62}-0.6_{-0.54}$ | $_{-7.07}-6.1_{-5.06}$ | $_{-0.7}-0.6_{-0.41}$ |
| 2 | $_{-0.48}-0.3_{-0.10}$ | $_{-2.65}-1.9_{-1.13}$ | $_{-1.30}-0.8_{-0.35}$ | $_{-3.04}-2.6_{-2.10}$ | $_{-1.12}-0.7_{-0.28}$ |
| 3 | $_{-0.61}-0.5_{-0.37}$ | $_{-5.50}-2.5_{0.57}$ | $_{-3.87}-1.0_{1.92}$ | $_{-3.87}-3.0_{-2.07}$ | $_{-0.76}-0.5_{-0.24}$ |
| 4 | $_{-0.47}-0.3_{-0.14}$ | $_{-5.30}-3.4_{-1.50}$ | $_{-1.60}-1.4_{-1.20}$ | $_{-21.76}-8.1_{5.50}$ | $_{-0.42}-0.4_{-0.32}$ |
| 5 | $_{-0.34}-0.3_{-0.16}$ | $_{-6.1}-3.5_{-0.99}$ | $_{-1.40}-1.3_{-1.10}$ | $_{-3.60}-3.2_{-2.80}$ | $_{-0.72}-0.6_{-0.44}$ |
| 6 | $_{-0.32}-0.3_{-0.19}$ | $_{-2.36}-2.0_{-1.73}$ | $_{-0.73}-0.7_{-0.60}$ | $_{-11.86}-5.5_{0.94}$ | $_{-0.67}-0.2_{0.28}$ |
| Experiments under cold conditions | | | | | |
| Short exposure | | | | | |
| $3t^{\circ}$ | $_{-0.47}-0.4_{-0.26}$ | $_{-2.78}-2.1_{-1.37}$ | $_{-1.34}-1.1_{-0.81}$ | $_{-3.86}-3.2_{-2.52}$ | $_{-2.81}-2.0_{-1.09}$ |
| Prolonged exposure | | | | | |
| $2t^{\circ}$ | $_{-0.39}-0.4_{-0.30}$ | $_{-12.58}-4.4_{3.80}$ | $_{-2.31}-0.6_{1.16}$ | $_{-2.76}-2.5_{-2.17}$ | $_{-3.51}-0.8_{1.91}$ |
| $4t^{\circ}$ | $_{-0.20}-0.2-_{0.12}$ | $_{-3.12}-1.3_{0.59}$ | $_{-0.82}-0.7_{-0.62}$ | $_{-4.62}-3.9_{-3.11}$ | $_{-1.47}-0.8_{-0.10}$ |

nomenon (along with the discontinuous structure of annuity curves and a stable variance level).

The regularity observed is unlikely to be unique for *Drosophila*. Variation of survival dynamics at the initial and subsequent life stages was reported for various biological species, including mammals and man [6]. As for the "multiphase" character, this feature is evident in the results of studies in *Daphnia* [10, 12, 13], certain insect species [14, 15], and some mammalian species [7].

## CONCLUSIONS

Thus, cold exposure of wild type *Drosophila melanogaster* strain (Canton-S) at the early stages of life led

to an increase in insect viability. This phenomenon is due to prolongation of the initial life stage and a delayed onset of the subsequent life stages. The phenomenon concerns the general problem of the relationship between different age periods. We consider this phenomenon to be of great theoretical interest.

The features of the aging phase delay phenomenon relevant for practical applications are the following: (1) the phenomenon is induced by relatively short-term exposure to the agent; (2) all individuals in a population are affected; and (3) the phenomenon can be manifested during all age periods (if the treatment duration is sufficient).

The obtained data enable a novel approach to research on the geroprotection problem. The use of other biological objects and modifying agents in an attempt to delay the emergence of certain manifestations of advanced age pathology, such as neurodegeneration and carcinogenesis [1], are of considerable interest for future studies.

## ACKNOWLEDGMENTS

This work was supported by grant NSh-9513.2016.4 from the President of the Russian Federation (grant for the support of leading research schools).

## REFERENCES

1. Anisimov, V.N., *Molekulyarnye i fiziologicheskie mekhanizmy stareniya* (Molecular and Physiological Mechanisms of Aging), St. Petersburg: Nauka, 2003.
2. Bychkovskaia, I.B., *Dinamika postradiatsionnoi gibeli biologicheskikh ob''ektov* (The Dynamics of Post-Radiation Destruction of Biological Objects), Moscow: Atomizdat, 1970.
3. Bychkovskaya, I.B., *Problema otdalennoi radiatsionnoi gibeli kletok* (The Problem of Remote Radiation Cell Death), Moscow: Energoatomizdat, 1986.
4. Bychkovskaia, I.B. and Mylnikov, S.V., On the discontinuous character of annuity curves. Communication 2. Analysis of the variability of annuity curve shape in *Drosophila melanogaster* of the *Canton-S* line, *Adv. Gerontol.*, 2016, vol. 6, no. 3, pp. 185–190.
5. Bychkovskaia, I.B., Mylnikov, S.V., and Mozhaev, G.A., On the discontinuous character of annuity curves. III. Two forms of viability variation in *Drosophila melanogaster, Adv. Gerontol.*, 2017, vol. 7, no. 1, pp. 29–34.
6. Gavrilov, L.A. and Gavrilova, N.S., *Biologiya prodolzhitel'nosti zhizni* (Biology of Life Duration), Moscow: Nauka, 1991.
7. Malygin, A.G., Age fluctuations in mortality of mice with mutation causing growth retardation, *Biochemistry* (Moscow), 2013, vol. 78, no. 9, pp. 1033–1042.
8. Mylnikov, S.V., Oparina, T.I., and Bychkovskaia, I.B. Discreteness of survival curves. I. Deviations from the Gompertz law in *Drosophila melanogaster* Canton-S strain, *Adv. Gerontol.*, 2016, vol. 6, no. 2, pp. 91–95.
9. Frol'kis, V.V. and Muradyan, Kh.K., *Eksperimental'nye puti prodleniya zhizni* (Experimental Methods for Life Prolongation), Leningrad: Nauka, 1988.
10. Bychkovskaya, I.B. and Sarapultseva, E.I., Special effects of low doses and life span of irradiated daphnids, *Int. J. Low Radiat.*, 2011, vol. 8, no. 1, pp. 35–41.
11. Motulsky, H. and Christopoulus, A., *Fitting Model to Biological Data Using Linear and Nonlinear Regression: A Practical Guide to Curve Fitting*, San Diego, Ca: GraphPad Software, 2002. http://www.graphpad.com.
12. Sarapultseva, E.I. and Dubrova, Yu.E., The long-term effects of acute exposure to ionizing radiation on survival and fertility in *Daphnia magna, Environ. Res.*, 2016, vol. 50, no. 1, pp. 138–143.
13. Sarapultseva, E., Malina, J., and Gorski, A., Radiation in low doses reduces life span of *Daphnia magna, Radioprotection*, 2011, vol. 46, no. 6, pp. S349–S353.
14. Tunçbilek, A.S., Ayvaz, A., Öztürk, F., and Kaplan, B., Gamma radiation sensitivity of larvae and adults of the red flour beetle, *Tribolium castaneum* Herbst, *Anz. Schaedlingskd.*, 2003, vol. 76, no. 5, pp. 129–132.
15. Watters, F.L. and MacQueen, K.F., Effectiveness of gamma irradiation for control of five species of stored-product insects, *J. Stored Prod. Res.*, 1967, vol. 3, no. 3, pp. 223–234.

*Translated by S. Semenova*