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Prevention of Myopia by Partial Correction of Hyperopia: A Twins Study

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Keywords: emmetropia; emmetropization; myopia; hyperopia; myopia prevention; feedback

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ABSTRACT

Purpose: To confirm the prediction of emmetropization feedback theory that myopia can be prevented by correcting the hyperopia of a child at risk of becoming myopic.

Methods: We conducted such myopia prevention treatment with twins at risk. Their hyperopia was partially corrected by one half at age 7 and in subsequent years until age 16.

Results: Hyperopia progressively decreased in all eyes as expected. None of the twins developed myopia. The spherical equivalent refractions of the followed eyes were +1 D and +1.25 D at age 16. Feedback theory accurately predicted these values.

Conclusions: The treatment of the twins with partial correction of their hyperopia was successful. Prevention of myopia with this technique is relatively simple and powerful. The use of this myopia prevention treatment has no adverse effects. This prevention treatment is indicated in children with a hyperopic reserve at risk of developing myopia.

Keywords: emmetropia; emmetropization; myopia; hyperopia; myopia prevention; feedback

INTRODUCTION

It is well known that most children are hyperopic at birth and that their hyperopia declines over the years to the point of reaching emmetropia. This decline and the resultant non-Gaussian distribution of refractive errors have been named emmetropization [1]. In some cases this trend continues after emmetropia is reached and myopia develops [2]. The decline may not start precisely at birth, but soon thereafter [3].

The term emmetropization usually refers to a mechanism regulating the long term focus of the eye towards emmetropia. There is now persuasive evidence indicating that regulation is by feedback control that extends well beyond the first years of life [4, 5]. In the simplest proposed form, this feedback control has been defined as a first order feedback system [5]. We will use and refer to such a first order feedback system in this report as “feedback theory.” Feedback theory has a mathematical equation that can predict the future refraction of an eye. Feedback theory does not require or depend on any physiological mechanism. It only requires that there is an optically produced signal related to refractive error that is fed back to alter the eye to achieve a set refraction. Feedback theory completely describes emmetropization by the transfer function $F(s) = 1/(ks+1)$ and this function is all that is needed for analytical or numerical calculations. See Appendix I. A transfer function is defined in the s-domain. Operation in the s-domain facilitates the derivation of general deductions analytically, such as the linearity of myopia progression [17]. To operate with specific patient refraction data in time (t), we transform from the s-domain to the t-domain using the Laplace transform and obtain the refraction = f(t) equations. Appendix I shows how to obtain the refraction equation with the transfer function F(s) when a correcting lens of power R is applied to the eye. The equations for each correction were derived in [5] and are the equations used in this paper.

It appears likely that the process of emmetropization in humans is most active during the early years of life, since the non-Gaussian leptokurtic distribution of refractive errors is established in 6 to 8 year olds [1, 6-7]. The influence of near work on the eye appears to affect young people older than 8, which implies that feedback operates after the age of 8 years. Slataper's study showed that average refractive error was a minimum in the late twenties [3].

Many believe that emmetropization is disrupted if hyperopia is corrected with lenses. Prescribing plus lenses to young hyperopes should indeed interfere with the process of emmetropization according to feedback theory. Some children are partially corrected as a compromise between the benefit of emmetropization and the alleviation of hyperopia-related symptoms.

Feedback theory predicts that the refractive error of hyperopic children that are fully corrected would not change substantially. It further anticipates that if hyperopia is under corrected, the greater the correction, the slower the hyperopic decline. The theory is supported by many cases confirming these predictions. Studies on children prescribed positive spectacle lenses show that emmetropization occurs more rapidly and more completely in those children who do not wear their prescription full time.

Hyperopia in very young children appears to be maintained if it is fully corrected and the spectacles are worn [8]. Accordingly, it was proposed that for those hyperopic children destined to be myopic, full correction could prevent myopia [9]. This report follows up on that recommendation and proposes using partial correction instead. Full correction would prevent myopia, but would also keep the hyperopia. If instead of full correction, we corrected partially, feedback theory shows that for every eye there is a particular under correction that will produce a decline of hyperopia that would stabilize at emmetropia.

There is great variability among clinicians in their choice of treatment of hyperopic children [10]. Partial, full, or no correction of hyperopia are treatments normally used. Therefore treatment with half correction would be within accepted clinical practice. In this study we conducted such myopia prevention treatment with twins at risk. Twins are generally exposed to the same environment and therefore the measurement of the effect of treatment is differential. The identical age is also an advantage because emmetropization may vary with age. If there are any environmental or age effects, they would affect them equally, avoiding different results.

The children at risk of developing myopia must first be identified. Indication of risk is the degree of their hyperopia [3, 19] or the refraction of the parents.

The probability of myopic parents having myopic children is high [2, 6, 11]. These risk factors add to a general factor based on the increasing prevalence of myopia [12]. Close work, computer use, indoors activities and familial tendency are further risk factors for myopia [2, 13, 14, 22]. More risk factors are included in the discussion.

MATERIALS AND METHODS

Selection was based on the following criteria: Fraternal twins being raised together in an identical environment; age 6 to 10; both twins had uncorrected low to mild hyperopia; uncorrected visual acuity was better than 20/30; and astigmatism was no greater than 0.75 D (diopters) for all four eyes; both parents were myopic of no more than 6 D; no tropias, binocular abnormalities or pathological condition were present in the parents’ and twins’ eyes; a commitment by the parents to participate for at least 9 years; parents could monitor compliance of spectacle wear by the twins. One pair of twins was found that met the criteria and parents were willing to participate in this myopia prevention treatment.

We partially corrected the hyperopia of the twin brothers (referred here as N and M) at age 7 and followed their refraction for 9 years. Treatment consisted in correction of their hyperopia by one half. This is not an unusual treatment and it is accepted by many professionals as management of child hyperopia.

The research protocol adhered to the Declaration of Helsinki for research involving human subjects. The parents of the children provided written consent to the treatment, screening and follow-up assessments. The choice of half correction was based on the feedback theory's general prediction that hyperopia so treated decreases at a rate slower than when it is uncorrected. The theory further estimated that emmetropia (defined as refraction between -0.25 D and +0.75 D) would be reached at around age 25 if the twins' right eyes hyperopia were so corrected.

The twins' eyes were refracted yearly (except for two missed years) under cycloplegia by standard subjective and retinoscopic techniques. The cycloplegic protocol was two drops of Cyclogyl (Cyclopentolate Hcl) 1% instilled 15 minutes apart and 45 minutes prior to refraction.

The same experienced optometrist did all the refractions with no knowledge of the study. After every refraction, spectacles were prescribed with half the sphere of the refractive error. Astigmatism was preserved in the prescribed corrections. The twins wore their glasses at all times.

The treatment continued till age 16. The feedback theory equations were then solved numerically to calculate the twins' refraction curves from all refractive data for their right eyes. The right eyes were chosen because they had the lowest hyperopia and the goal of this study was to avoid myopia in all eyes, thus if myopia was avoided for the right eyes, it would also be avoided to a great certainty for their left eyes that were more hyperopic. All references here are to right eyes unless otherwise noted. The left and right eyes were correlated and followed a similar course.

RESULTS

Hyperopia progressively decreased in all four eyes as expected. None developed myopia. Figs. 1 and 2 depict the spherical equivalent refractive errors of the eyes of twins N and M respectively from age 7 to 16 and the predicted curves for their refraction. The spherical equivalent refractions of the eyes of twins N and M were +1 D and +1.25 D respectively at age 16. The model predicts that the twins N and M would be at +0.75 D and +0.29 D respectively at age 25 if treatment continued.

The hyperopia of twin M decreased almost 3 D from +3.75 D to +1.25 D, substantially more than twin N as feedback theory predicted, Fig 2.

DISCUSSION

Feedback theory teaches that the refraction of the twins if they had been fully corrected at age 7 would not have changed significantly. It further informs that if under-corrected, the greater the correction, the slower the hyperopic decline. The same is true for any child of any age or degree of hyperopia. The theory also predicts the twins' eyes refractive development and asymptotic stabilization if they stop wearing any correction at age 16. In that case, twin N would be at +0.4 D at age 23, while twin M would reach 0 D at that age. The refraction of twins N and M would then stabilize at +0.2 D and -0.74 D respectively.

The twins were at risk of developing myopia. Hyperopia can decrease about 3 D in ten years, even when partially corrected, as demonstrated by twin M, Fig 2. Myopia can develop or progress even in the twenties and thirties [14, 17, 18]. Slataper's large study of 33,051 cycloplegic refractions showed an average hyperopia of almost 4 D in children of age 7 and that the average refractive error was minimum around age 30 [3]. According to the "prognostic significance" that Slataper attached to his data based on its average change, our twins N and M would reach a refractive error of -1.8 D and +0.5 D respectively at age 32. In a group of 183 children (363 eyes) of age 4 to 19, the mean refractive error at age 4 was found to be +2.86 D and was gradually decreasing to reach 0 D at the age of 14 [15]. Our twins were close to this mean value at age 7. In a group of 4512 children of ages 6 to 13, 414 crossed from hyperopia to myopia in the few years (1 to 7) that they were followed. The authors of the study concluded that the children's degree of initial hyperopia was related to their probability of becoming myopic in the period they were followed and suggested to use it as a general prognosticator [19]. That study, which partially contradicted their previous work [2], is of little assistance to predict end-myopia because surely many more hyperopic children became myopic in the years after follow-up ended.

These studies are based on average trends and cannot tell us how the refractive development would be for individual children. It was nevertheless reasonable to expect that the twins were at risk of becoming myopic at age 16 or later. The twins also met other risk factors- the parents were myopic and well-educated, living in a typical North-American urban setting, where early education is the norm and includes extensive reading, daily near-vision homework and computer use indoors, in addition to frequent use of modern electronic devices at close distance.

We also had information about the twins' paternal grandparents and grand-grandparents. They were at least one of each myopic. It is therefore probable, independently from feedback theory prediction, that their refractions of +1 D and +1.25 D at age 16 were due to the treatment of their hyperopia. Feedback theory offered predictions that fit their refractive data accurately. The predictions factored in their partial correction of hyperopia.

Feedback theory also anticipates that near work is myopizing because it is equivalent to wearing a minus lens for distance vision. Wearing a minus lens of a given power a percent of the time is the same as wearing a lens of that power reduced by the same percent full time [16].

We can use feedback theory to get a prediction curve for any corrective scheme. As an example, let’s assume that twin N was never corrected for his hyperopia, had an increased near work demand equivalent to wearing a -1 D lens, and was fully corrected for his subsequent myopia every time it increased by 0.25 D. Fig. 3 shows the result. Twin N would have crossed from hyperopia to myopia at age 12 and reached 1 D of myopia at age 18. If his near work continued at the same level, his myopia would progress. Notice that feedback theory predicts a linear progression or “myopia depression” while corrected [17].

Numerous studies have demonstrated that atropine is effective in slowing myopia progression in children, even at low concentrations of only 0.01% [23]. Atropine and the strategy described here both achieve a slowing in the progression of ametropia in the negative or myopic direction. The basis of the atropine effectiveness may be the same as in this study, the use of plus lenses. Although atropine treatment and myopia progression rate are associated, it has not been demonstrated that atropine itself is the ultimate cause of the reduction in the rate of progression rather than its effects. Feedback theory offers an alternative cause. The theory predicts a reduction in myopia progression rate when using atropine due to its effect on accommodation. Atropine reduces the accommodative amplitude, which requires that those so treated remove their glasses and/or use a plus addition to focus near objects [23, 24]. Atropine users are therefore uncorrected, under corrected, or plus corrected during near vision. In either case, feedback theory predicts a reduction in the progression rate of myopia, as several investigators confirmed [25-27]. Chia et al results [23] also support the feedback theory explanation for the reduced progression rate. They used three different concentrations of atropine for three groups of patients and noted the percent of patients in each group that requested plus addition. The rate of progression of myopia was proportionally less in the groups with higher percent of plus lens users, as feedback theory predicts. Many patients are reluctant to use atropine for several reasons, such as blurred near vision and photophobia derived from undesirable cycloplegia and mydriasis, costs, difficulty obtaining the compounding, risk of developing glaucoma, and other adverse effects. An examination of the reason and extent of atropine's effects is therefore needed to determine if it is worth the risks. Correcting hyperopia offers to evade myopia rather than to combat it. Avoiding myopia, even at the risk of remaining hyperopic is an outcome that compares favorably to the temporary effect of atropine treatment.

CONCLUSIONS

The treatment of the twins with partial correction of their hyperopia was successful because the goal of preventing myopia was achieved. The parents were very satisfied with the results. Even if the twins no longer wear any correction, their right eyes are expected to be around 0 D at age 23. At that age the probability of developing any significant myopia is low, based on theory and experience.

To demonstrate that partial correction of hyperopia is also successful in preventing myopia in the general population, a larger number of patients with a control group is desirable. We encourage further studies or treatment. The treatment and results here are supported by a theory that has proven accurate before with many eyes.

Prevention of myopia with this practice is relatively simple and powerful if started at an early age. Although the fraction of hyperopia that must be corrected for optimal results depends on the child, for initial hyperopia and age close to that of the twins, a value of 50% is indicated. For higher or lower hyperopia, a proportional adjustment must be made. Also the older the child the greater the percent of corrected hyperopia must be.

The invariance of fully corrected hyperopia is a characteristic of the feedback theory. It suggests that if hyperopia is very low, an immediate full correction is indicated to maintain it and prevent a forthcoming myopia. In contrast, usual management of such hyperopia is to leave it uncorrected. Ideally, and for optimal results, the reduction of hyperopia should be closely monitored and recorded for several years. With this information, the feedback equation can make more accurate predictions of future refraction and the fraction of hyperopia corrected could be adjusted accordingly. A refined design treatment could provide the proper correction for each eye so that both eyes stabilize at the same desired refraction.

Ophthalmologists and optometrists would need to select patients very carefully before prescribing the plus lenses. The difficulty is determining who is at risk of developing myopia. Several factors should be weighted, in number and degree. Risk factors are myopic parents and even siblings, hyperopia at the time of selection, rate of change, age of child and time engaged in near vision, and living location as certain regions in the world have very high incidence of myopia. Feedback theory may indicate who is a candidate more accurately if past refractions are available. A patient that is not considered a candidate may become one at a later time if the hyperopia decreases quickly or other factors emerge. The risk of prescribing plus lenses to a patient that would become emmetropic without them is that the patient would remain hyperopic.

This result is predicted by feedback theory and by those who found that correcting hyperopia hinders emmetropization.

The use of this myopia prevention treatment of hyperopia has no adverse effects because it has been used for many years by many practitioners to avoid interference with emmetropization and other reasons without problems. Therefore the treatment is indicated in children with a hyperopic reserve at risk of developing myopia.

COMPLIANCE WITH ETHICAL STANDARDS

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study. Additional informed consent was obtained from all individual participants for whom identifying information is included in this article.

Conflict of interest. The authors have no proprietary or financial conflicts of interest.

APPENDIX I

The feedback system output to an input lens of R diopters in the t-domain is the inverse Laplace transform of the output in the s-domain, which in turn is the transfer function times the step input in the s-domain:

$$o(t) = L^{-1}\{O(s)\} = L^{-1}\{I(s)F(s)\} = L^{-1}\{L[i(t)]F(s)\} =$$

$$L^{-1}\{R / [s(1+ks)]\} = R[1 - \exp(-t/k)] \qquad \text{Eq. (1)}$$

where t is time, k is the time constant, I(s) is the step input in the s-domain, i(t) is the step input R in the time domain, O(s) is the output in the s-domain, and o(t) is the output in the t-domain, L is the Laplace transform and L^{-1} is the inverse Laplace transform.

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FIGURE LEGENDS

Fig. 1. Refractive errors of twin N corrected by 50% at ages 7, 8, 10, 11, 13, 14, 15 and 16 (diamonds) and the prediction by feedback theory (continuous line). The refractive error *R(t)* in diopters is indicated in the y axis and the x axis represents age *t* in years.

Fig. 2. Refractive errors of twin M corrected by 50% at ages 7, 8, 10, 11, 13, 14, 15 and 16 (diamonds) and the prediction by feedback theory (continuous line).

Fig. 3. Refractive prediction (continuous line) for twin N if his hyperopia had never been corrected, he had an increased near work demand of 1 D and were corrected for his myopia every time it increased by 0.25 D (crosses denote the four corrections used for calculation).

Fig. 1

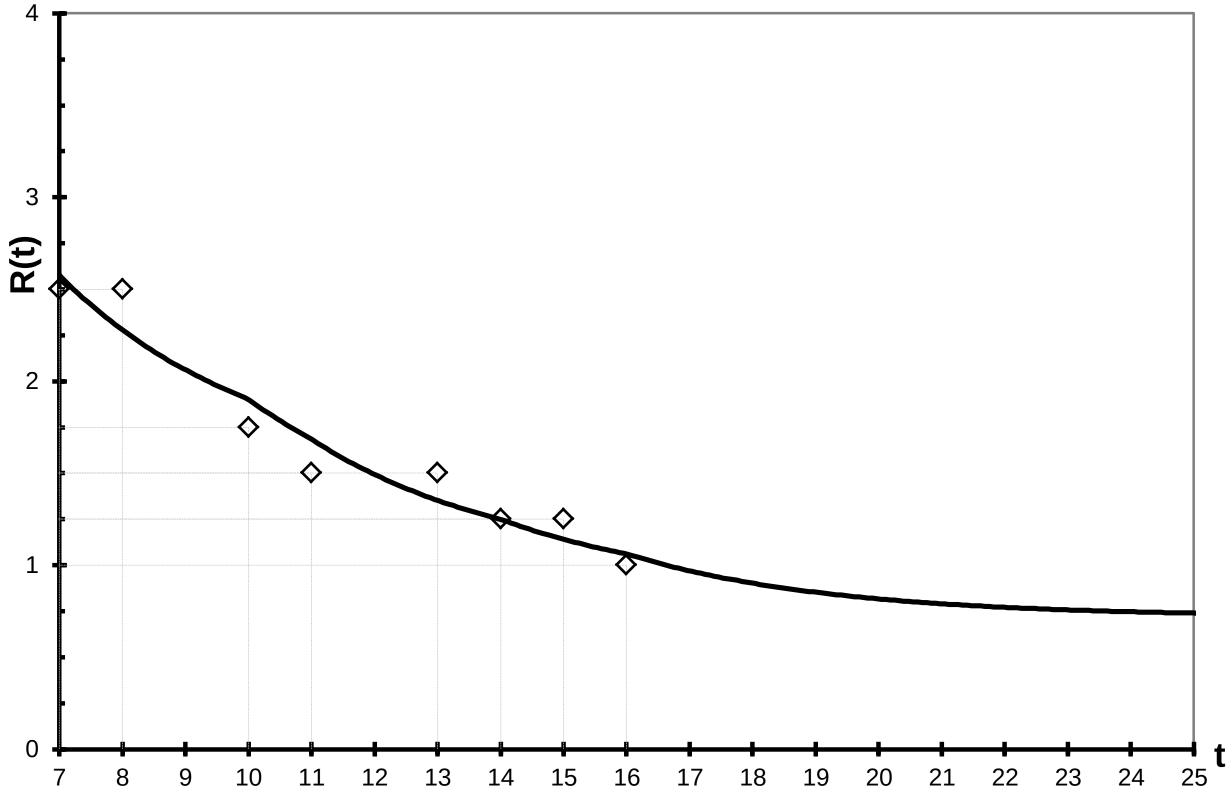


Fig. 2

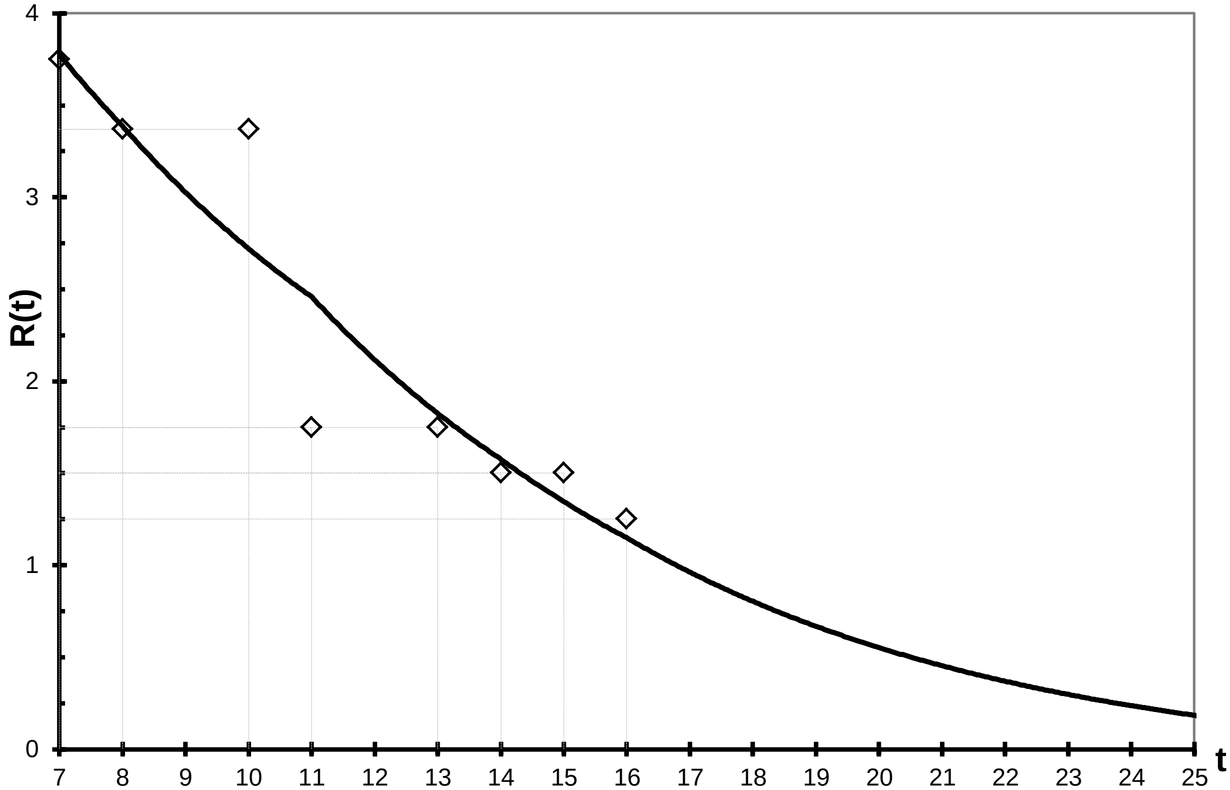
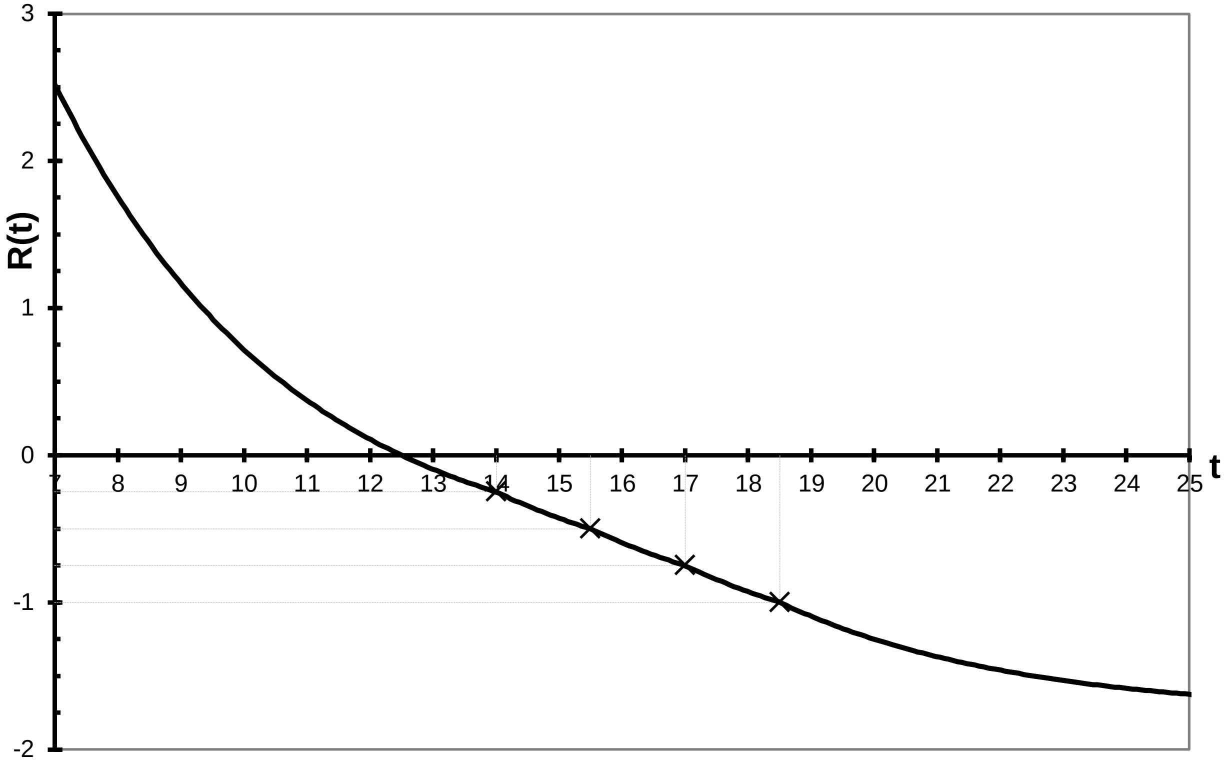
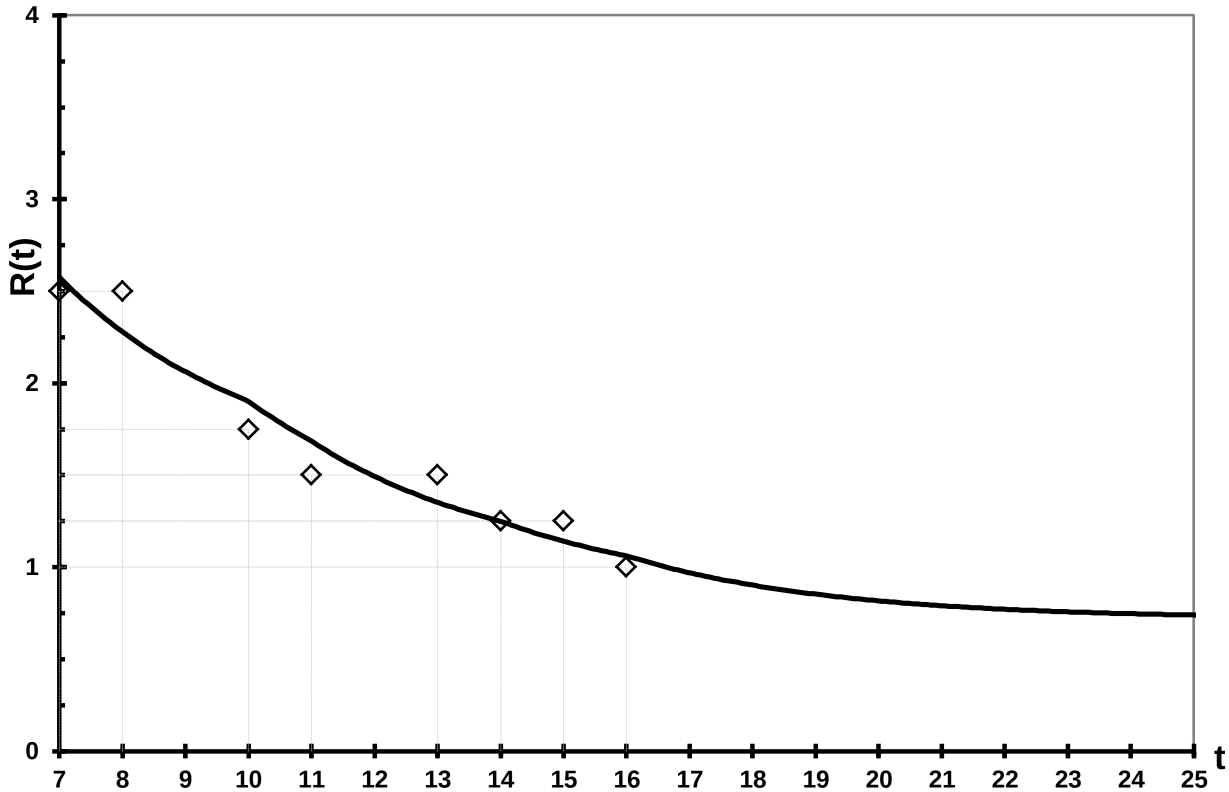


Fig. 3





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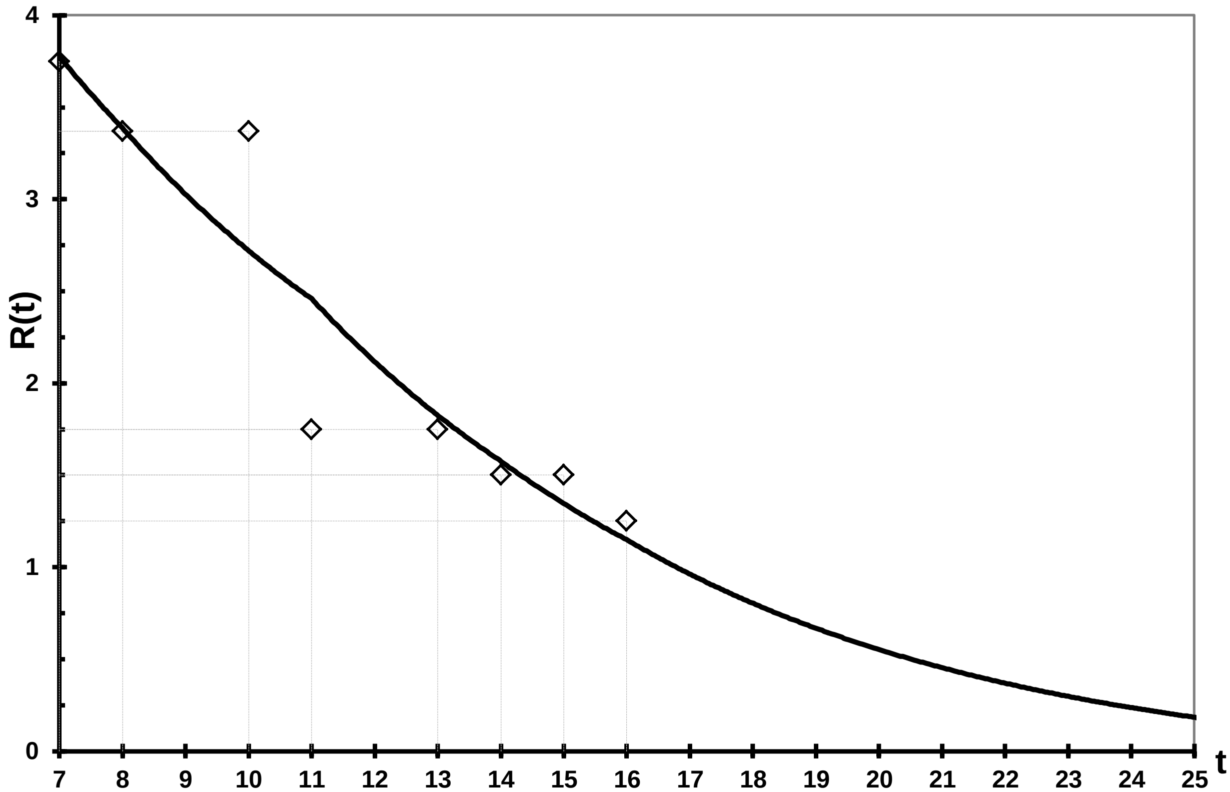

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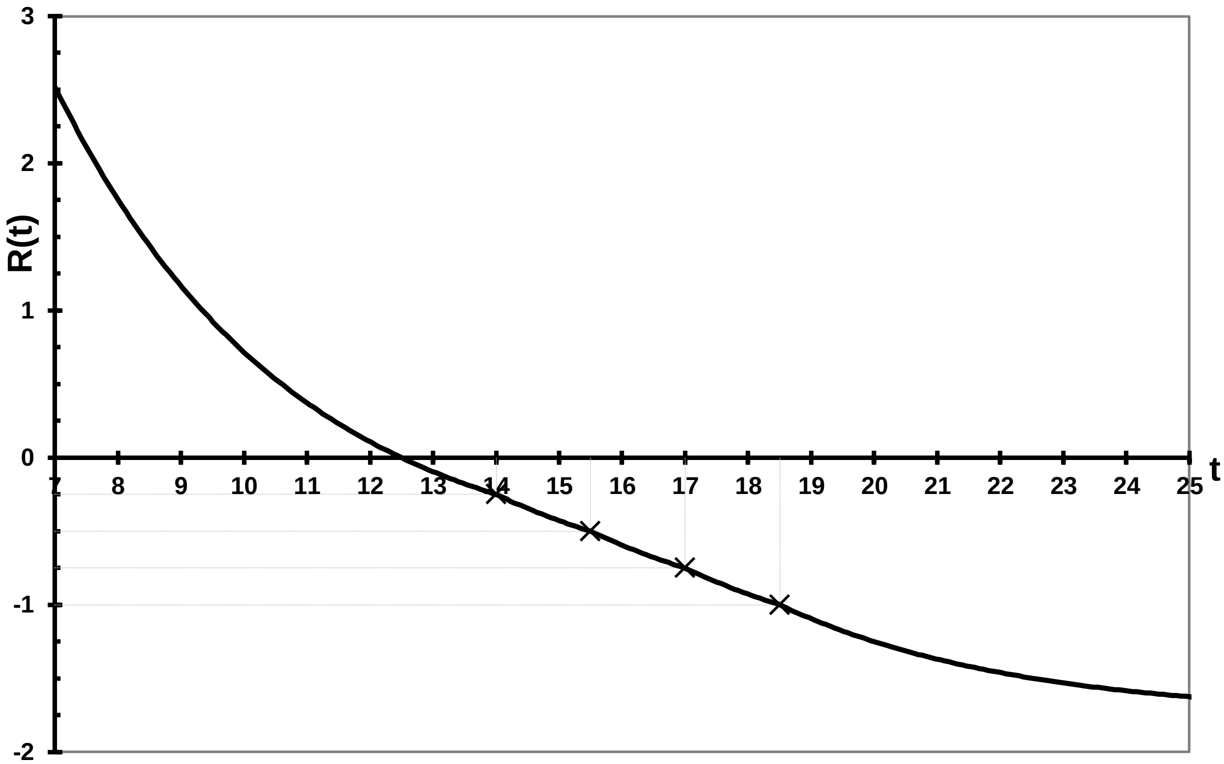
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