1. INTRODUCTION

Within the scope of a study carried out by the Austrian Board of Trustees for Traffic Safety on the comparison of safety in Austrian tunnels [1.2.3] the cause of accidents between 1999 and 2003 came under scrutiny. As a result it was determined that the cause of six out of ten accidents in the transit domain of tunnels was due to a lack of vigilance (inattentiveness and distraction), human error (especially due to a lack of safe distance from the vehicle ahead) and misjudgment (in regard to vehicles driving ahead or stationary vehicles) on the part of the motorists. Interestingly, the cause of these accidents was marginally connected with inadequate tunnel lighting which substantially reduces motorist’s visual perception and concentration.

The lightest areas of a tunnel (ceiling lights, the illuminated boundary, the luminous information and traffic signs, head-lights, tail-lights) all direct the eye and attention, which distracts the motorist from what should be the centre of attention, namely the flow of traffic. The brightly illuminated areas of the tunnel are embedded in a relatively dark environment which cultivates physiological and psychological glare phenomenon and due to the high contrast, light areas seem lighter and dark areas seem darker. This rouses the motorist’s desire for visual orientation when driving through a tunnel and diverts attention again to the lightest area. A vicious circle is established.

As a result of this study, it was also ascertained by the authors that in the tunnels entrance domain of 51 to 250 meters, 76% of all accidents occurred due to rear-end collisions. This also accounts for more than half (55%) of accidents which occurred in the rest of the transit domain. The main reason for these accidents is a lack of distance held to the vehicle ahead. Tunnel lighting which would generate an even vertical light could, in this case, also make a decisive contribution in reducing the number of accidents. However, only horizontal parameters are to be found in tunnel lighting standards.

In conclusion, we would like to mention that social-demographic population growth is a deciding argument for improvement of tunnel lighting. Forecasts for the European Union signalize that in about 40 years one third of the population will be over 65 years old. Although older motorists only drive about 40% of the distance of working motorists [5], many do possess a driver’s license. In 2003 for example, 85.7% of men and 47.7% of women in Germany over 65 years old, possessed a driver’s license with the potential possibility of driving a motor vehicle [Fig.1]. Together with increasing age, there is also an increase in the danger of human error on the part of the motorist due to a deficiency in perception (e.g. degeneration of eyesight, increased dazzle or a reduction in color perception). Current studies [4] suggest the double risk factor by older motorists [Fig.2].
A laboratory study, carried out in the “Kompetenzzentrum Licht”, indicated distinctly that a deficit in the perception of detail among older people could be partially reduced by means of higher roadway luminance.

2. LABORATORY STUDY ON TUNNEL LIGHTING

During a four-year laboratory study carried out in the Kompetenzzentrum Licht, 204 people were tested (31 of which were over 50 years of age) on the influence of different light environments in tunnels on the perception of detail, motion and space. It is precisely the changes in these perception parameters which should provide information as to which light intensity (road surface luminance of between 2 and 28 cd/m² was investigated) and light distribution (both continuous and punctuated ceiling lighting systems were investigated) provided the utmost attentiveness and the best speed variation-assessment of the vehicle ahead. The laboratory set-up ensured that each person was tested under equally good research conditions. The research was carried out using a projector [Fig.3] to simulate a tunnel with glare-free ceiling lighting (the maximum luminance of the projection amounted to 130 cd/m²) allowing for colors to be well identified and for a balanced distribution of light between the road surface and tunnel walls (it was about twice as bright in the central visual field as in the peripheral area) [Fig.4]. Such a research set-up makes it possible to exclusively record the influence of different light environments, characterized by light intensity and light distribution.
Subject to the assigned visual task during the laboratory study, the following conclusions were reached: for a significantly improved perception of detail for younger motorists, a road surface luminance of 7 – 8 cd/m² is necessary. For motorists over 50 years of age, twice as much is necessary for a good perception of detail (approx. 15 cd/m²). Furthermore, brighter conditions amplify the field of vision and the area of higher attentiveness. Light distribution plays an extraordinary role in optimizing perception of motion and space. A continuous ceiling lighting system (with a luminance of 7 cd/m²) enables a significant improvement in space and motion perception performance. Overall, it was concluded from the study that demands should be made for road surface brightness to be increased to at least 7 cd/m², together with installation of linear lighting systems in order to achieve a higher longitudinal evenness in horizontal and vertical directions.

3. VISIONS FOR TUNNEL LIGHTING

Last year, the ASFINAG commissioned the Lichtakademie Bartenbach to carry out a concept study, the objective being, installation of innovative lighting concepts in tunnels. During the course of this study a conventional tunnel lighting system [Fig.5, Fig.7] was compared to various other lighting systems [Fig.6, Fig.8].

**Fig.5:** Conventional lighting **Fig.6:** Lighting vision

**Fig.7:** Conventional radiation principle **Fig.8:** Radiation principle vision
This new concept was based on findings of the Kompetenzzentrum Licht laboratory study, together with a compilation of theoretical foundations and basic principles of motorist’s visual perception when travelling through a tunnel, (e.g. recognition of contrasts, depth of accommodation and constancy of adaptation), and results in a high, even vertical lightness in the tunnel.

Apart from an innovative light distribution, this concept study implemented the application of LEDs for a tunnel lighting system [Fig.9].

With the application of LEDs, motorist’s color perception during the journey through the tunnel will be optimally assisted. In addition, the small size of the lamps together with a special asymmetrical distribution of light (achieved through a lens system) makes it possible for directing light to be achieved by the luminance distribution, and not through the lights or road markings.

A subsequent result of this concept was the development of a prototype for LED tunnel lighting. The prototype fulfills all demands of the Austrian Tunnel Lighting Standards.

4. LITERATURE