The Effect of Tram Driver's Cab Design on Posture and Physical Strain

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Abstract. The ergonomic quality of a tram driver's cab is essential to ensure the physical well-being of the drivers and the general attractiveness of the workplace. We investigated the ergonomic quality of the cabs of two different trams in a field study during real operation. The results show that the experienced physical strain differs significantly between the two trams. A video analysis relates this to different posture and movement patterns. The main factor for these differences is the position of the main control panel, which needs to comply with visibility requirements according to DIN 5566. However, our study shows that an ergonomic workplace cannot be accomplished by only pursuing isolated factors, instead the interaction of all relevant factors has to be considered.

Keywords: Tram driver's cab · Field study · Physical strain · Ergonomic design

1 Introduction

Trams play an important role in the public transportation sector in Germany, for many years the number of passengers has constantly been increasing [1]. In comparison to other European countries, Germany has by far the most light rail and tram systems [2]. However, public transportation companies in Germany are more and more confronted with the challenge of demographic change. On average, the workforce is getting older and older and it is becoming increasingly difficult to recruit junior staff [3]. In order to keep older drivers healthy at work for a longer period of time and to recruit new people for the profession of tram driver, it is essential to provide an attractive workplace. A central element of the attractiveness of the workplace of a tram driver is the ergonomic quality of the driver's cab. Nowadays, trams (US: streetcars) can easily achieve service lives of 25–30 years. For tram drivers, the design of the cab determines their workplace, often for decades. This makes ergonomic considerations in the design process of a cab an even more important topic.

The central standard for the design of a driver's cabs for railway vehicles in Germany is DIN 5566, which consists of three parts (for standards used in other European countries see [4]). Part 1 [5] deals with general requirements for railway vehicles, part 2 [6] formulates additional requirements for standard gauge railway vehicles. Part 3 deals with additional requirements for urban and suburban rolling stock, which comprises also trams [7].

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With respect to ergonomic questions, the standards provide requirements regarding anthropometry, noise, seat design, visibility and the design of the control panel (design, reachability and positioning of control elements). However, the requirements are sometimes only “minimum requirements” and/or have a recommendatory nature. This gives degrees of freedom for the concrete design of the tram cab. While European railways have made efforts to standardize the design of the whole driver’s cab (DB-Einheitsführerstand, European Driver’s Desk), tram driver’s cabs nowadays are all designed differently. Therefore, it is quite interesting to compare differently designed cabs with regard to their ergonomic quality.

The tram operation company of Karlsruhe (Verkehrsbetriebe Karlsruhe, VBK) approached our institute with the aim of learning more about specific factors which determine the ergonomic quality of a tram driver’s cab and which therefore should be taken into account for the development of future trams.

2 Methods

2.1 Tram Types

In our study, we compared the two different tram types that are currently in operation at VBK:

1. Type: NET2012
   Manufacturer: Vossloh Rail Services, Stadler Rail
   Number of trams at VBK: 75 (2018)
   Start of operation: 2014
2. Type: GT6-70D/N
   Manufacturer: DUEAWAG, Siemens
   Manufacturer: Stadler Rail (until 2015: Vossloh Rail Services)
   Number of trams at VBK: 45 + 25 (longer version)
   Start of operation: 1995

2.2 Measurement Devices

For the analysis of the work processes and the accompanying body postures, the driver’s cab was equipped with the following measurement devices (see Fig. 1 left):

- Two video cameras (GoPro Hero 3+ , GoPro Hero 5 black). One camera was positioned on the control panel to record the frontal view, the other camera was positioned on the left window to record the sagittal view of the driver.
- Two pressure distribution mats (novel pliance©). The mats were placed on the seat and on the left armrest (the results of the pressure distribution mats are not part of this article).

2.3 Materials

In order to assess driver's subjective physical strain, we used a map of the human body (according to [8]). The map divides the body into five regions: left forearm, left shoulder, neck, upper back, lower back (see Fig. 1 right). The drivers were asked to give an estimation of the experienced strain for each body region on a ten-point rating scale (1 = no strain; 10 = extreme strain).

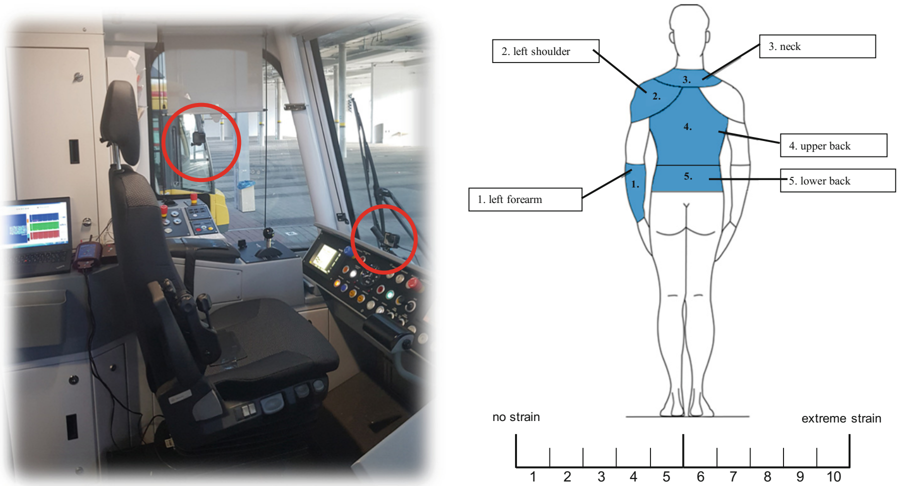

Fig. 1. (left) Location of the video cameras in the NET2012. (right) Body map with five highlighted body regions that were used for the measurement of the experienced physical strain.

2.4 Route

The route started in a northwestern district of Karlsruhe (Neureut) with a rather low passenger volume and with dedicated tram tracks (i.e. the tracks are separated from other vehicles/cars). After about 15 min, the route entered Karlsruhe City. Here, the passenger volume is generally much higher and the tram runs on tracks that are partly shared with other vehicles. After about 45 min, the route ended in a northeastern district (Waldstadt). Here, the passenger volume is again rather low and the tram operates on dedicated tracks. After a scheduled break, the tram returned to Neureut on the reverse route. The first part of the route is called outward ride, the second part is called inward ride.

2.5 Subjects

A total of six people participated in the study. All participants were regular tram drivers of the VBK and were familiar with both, the two tram types and the route.

2.6 Procedure

The tram rides took place on four successive days. Every participant performed two rides: one with the NET2012 and one with the GT6-70D/N. The rides on the two tram types took place on different days, the route, however, was always the same (see above). We tried to keep relevant environmental influences such as visibility conditions (day/night) and passenger volume comparable by driving in the same time slots on each day of the measurements (09:15–14:15).

At the beginning of each ride, participants were welcomed at the starting station in Neureut and asked to read and sign a consent form. Afterwards, they had the possibility to adjust the seat and assume their regular driving position. The examiner showed the drivers the body map and the rating scale and asked for a first estimation of their subjective physical strain in each body region, which served as a baseline measurement. The subjective physical strain was assessed approx. every 15 min at predefined stations. For this purpose, the examiner entered the cab while passengers were exiting or entering the tram and asked for a quick oral assessment. Except of these short interruptions, the drivers could operate undisturbed in their cab. After the return to the starting station in Neureut, the driver was asked to give a last subjective assessment. Finally, some body dimensions (e.g. body height) were measured.

2.7 Data Analysis

The subjective data were averaged across all drivers. Due to the small sample size, no statistical test was calculated. Instead, we performed a descriptive analysis of the data with different graphs.

The video data were analyzed by two independent raters. With the help of a specially designed Excel-Sheet, the raters counted the frequency of the occurrence of specific body postures.

3 Results

3.1 Subjective Physical Strain

First, we compared the subjective physical strain that drivers experience in the two different trams. In the GT6-70D/N, drivers show almost no physical strain in any body region during the entire ride (see Fig. 2 right). In contrast, drivers show signs of physical strain after about 30 min in the NET2012. The affected body regions are the neck and the left shoulder. Both body regions show a slow but constantly increasing trend until the end of the ride (see Fig. 2 left).

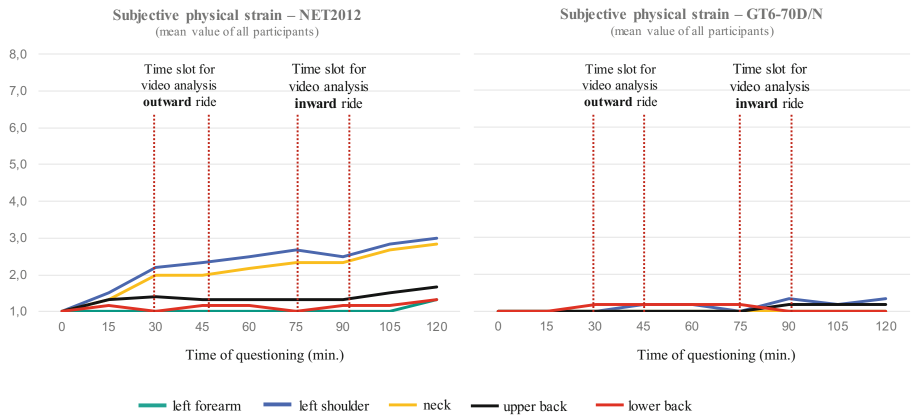

Fig. 2. Mean subjective physical strain for every body part across all $N = 6$ tram drivers for the NET2012 (left) and the GT6-70D/N (right). The dotted lines mark the time slots for the video analysis.

3.2 Video Analysis

In order to investigate the reason for the increase of physical strain in the NET2012, we performed a thorough video analysis of the body movements and postures. Due to the fact that an analysis of the entire ride would be too time consuming, we chose a total recording time of 30 min per ride. This time consists of two separate time slots of 15 min each. The start of the first time slot corresponds to the first increase of physical strain (about 30 min after the start of the outward ride, see Fig. 2). The second time slot comprises the same part of the route on the inward ride (about 75 min after the start, see Fig. 2).

We identified two movements which differ considerably between the two tram types and which are therefore very likely to cause the physical strain: neck flexion and trunk flexion.

Tables 1 and 2 show the results of the neck and trunk flexions, respectively. In the GT6-70D/N, drivers perform on average 74.2 neck flexions and 0.2 trunk flexions during the observed 30 min time slot. In the NET2012, drivers perform 129.3 neck flexions and 39.7 trunk flexions. Both movements occur much more frequently in the NET2012 than in the GT6-70D/N (neck flexion: +74.3%, trunk flexion: +19750%). Particularly, while the GT6-70D/N requires nearly no trunk flexions during normal operation, the tram drivers perform this movement regularly in the NET2012.

Table 1. Observed frequency of neck flexions during the 2 × 15 min video for the NET2012 (NET) and the GT6-70D/N (GT). The table shows the mean frequency across all $N = 6$ tram drivers. Minimum and maximum show the frequency of the drivers with the most and with the least neck flexions. % cf. shows percentage difference of neck flexions between the two tram types. The interpolated data show the estimated frequency of neck flexions for 1 h, 8 h (work day) and 40 h (work week).

Neck flexion	Overall (2 × 15 min.)		% cf.	Interpolation					
				1 h		8 h		40 h	
	NET	GT	NET to GT	NET	GT	NET	GT	NET	GT
Mean	129.3	74.2	+74.3%	259	148	2069	1187	10344	5936
Maximum	152	117							
Minimum	95	17							

Table 2. Observed frequency of trunk flexions during the 2 × 15 min video for the NET2012 (NET) and the GT6-70D/N (GT). The table shows the mean frequency across all $N = 6$ tram drivers. Minimum and maximum show the frequency of the drivers with the most and with the least trunk flexions. % cf. shows percentage difference of trunk flexions between the two tram types. The interpolated data show the estimated frequency of trunk flexions for 1 h, 8 h (work day) and 40 h (work week).

Trunk flexion	Overall (2 × 15 min.)		% cf.	Interpolation					
				1 h		8 h		40 h	
	NET	GT	NET to GT	NET	GT	NET	GT	NET	GT
Mean	39.7	0.2	+19750%	79	0.4	635	3	3176	16
Maximum	61	1							
Minimum	7	0							

4 Discussion

The subjective data show that drivers experienced physical strain when interacting with the NET2012. The strain experience arose about 30 min after the start of the ride and exhibited a constantly increasing trend until the end of the ride. The affected body regions were primarily the neck and the left shoulder. The strain values reached a level of about 3 and were thus still located on the lower end of the 10-point rating scale. However, this value has to be seen in the context that we only observed a 1.5 h ride at the beginning of the workday. It can be expected that a longer ride would provoke higher strain levels. Over the years, this strain may accumulate and likely lead to health issues. The comparison with the GT6-70D/N reveals that the reason for the higher strain values in the NET2012 lies in its ergonomic design, as drivers in the GT6-70D/N showed almost no signs of physical strain.

The video analysis shows that there is a huge difference in the way drivers physically interact with the two tram models. The operation of the NET2012 requires significantly more neck and trunk flexions. These differences seem to be a plausible explanation for the higher strain values in the NET2012.

A closer look at the design of the two cabs revealed one major difference: the placement of the main control panel. In the NET2012, the control panel is located further down than in the GT6-70D/N. This requires trunk flexions to reach the control elements. On top of that, even the mere look at the control panel in the NET2012 requires a flexion of the neck.

As mentioned in the introduction, DIN 5566 formulates visibility requirements. To comply with the standard, a tram driver has to be able to see a parallel contour of 1.20 m height located 30 cm in front of the tram. The visibility of the parallel contour depends on three factors: (1) the distance between the driver and the front end of the tram, (2) the position of the eyes of the drivers (seat height) and (3) the location and shape of the control panel. One main difference between the two trams is the seating position. While the minimum seat height in the GT6-70D/N is located 122.5 cm above track level, the minimum seat height in the NET2012 is located 146.5 cm above track level. In order to comply with the visibility requirements, the control panel in the NET2012 has been installed further down which comes at the cost of a reduced usability.

5 Conclusion

Our results show that it is possible to design a cab in a way such that the driver experiences nearly no physical strain during regular operation. For the NET2012, this could be accomplished by the design of a more sophisticated shape for the control panel, which can be located further up without impairing the visibility. In general, a mere focus on isolated ergonomic factors has to be avoided but instead the interaction of different factors has to be considered. Only such a systems approach ensures the ergonomic quality of a tram driver's cab which contributes to both, the attractiveness of the workplace and the physical well-being of the drivers.

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