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Effects of Rearward Displays in Highly Automated Shuttles on Following Traffic

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Introduction

The successful integration of **highly automated shuttles** (HASs; SAE Level 4, [1]) into mixed traffic and the associated benefits for road safety or easy access to mobility depends on HAS **acceptance** [2]. Currently, HASs' driving behavior is characterized by travel speeds below 20 km/h and frequent unexpected stops for rearward traffic [3], which may lead to congestion, frustrations of following road users, and risky overtaking maneuvers. Since this driving behavior of HASs is rather unfamiliar to human road users, **transparency regarding future maneuvers** needs to be increased during these encounters to ensure **road safety**. Therefore, rearward **countdown displays** (CDD) might be applied as a form of external HMIs (eHMIs) to increase the **situation awareness of following road traffic** [4]. This might impact HAS' acceptance and trust in these systems.

Method

Participants:

N = 122 (85 women, 37 men)
M_{age} = 26 years (SD = 9.51)

Dependent variables:

Understanding/predictability [5], perceived quality of information [6], acceptance [7], general preference

Research Design:

Video-based online study; participants experienced virtual rides in a passenger car following a HAS traveling at 18 km/h, implemented as a within-subject design with repeated measures:

- 1x3: ***mode*** (incl. baseline condition)
- 2x4: ***mode**frequency***

Table 1. Factor levels of the 2x4 design

Frequency of Updates	***Mode*** of Countdown Display	
	"time"	"distance"
"1.0 Hz"	1 s	5 m
"0.5 Hz"	2 s	10 m
"0.2 Hz"	5 s	25 m
"0.1 Hz"	10 s	50 m

Example screenshots of the video material

Start of video sequence; passenger car is about to slow down to 18 km/h as it reaches the HAS.

Required follow-up scenario due to narrow lane and oncoming traffic; onset of CDD presentation until the next stop (e.g. "distance" conditions)

HAS approaches stop, displaying final step of CDD (e.g. "time: 1 s" condition) accompanied by decelerating, braking light, and turn indicator. Followed by CDD assessment.

Results

- Use of CDD significantly preferred over baseline, independent of CDD's mode
- Significant mode*frequency interaction, plus evidence that higher update frequencies are favored
- Similar findings for all dependent variables

Table 2. ANOVA results for **general preference**

Design	Factor	df	F	p	n_p^2
1x3	mode	1.438, 173,972⁺	36.035	< .001	.229
2x4	mode	1, 121	0.008	.928	.000
2x4	frequency	1.872, 226.466⁺	18.631	< .001	.133
2x4	mode*frequency	2.536, 306.916⁺⁺	18.662	< .001	.134

Note. ⁺ Greenhouse-Geisser adjustment, ⁺⁺ Huynh-Feldt adjustment

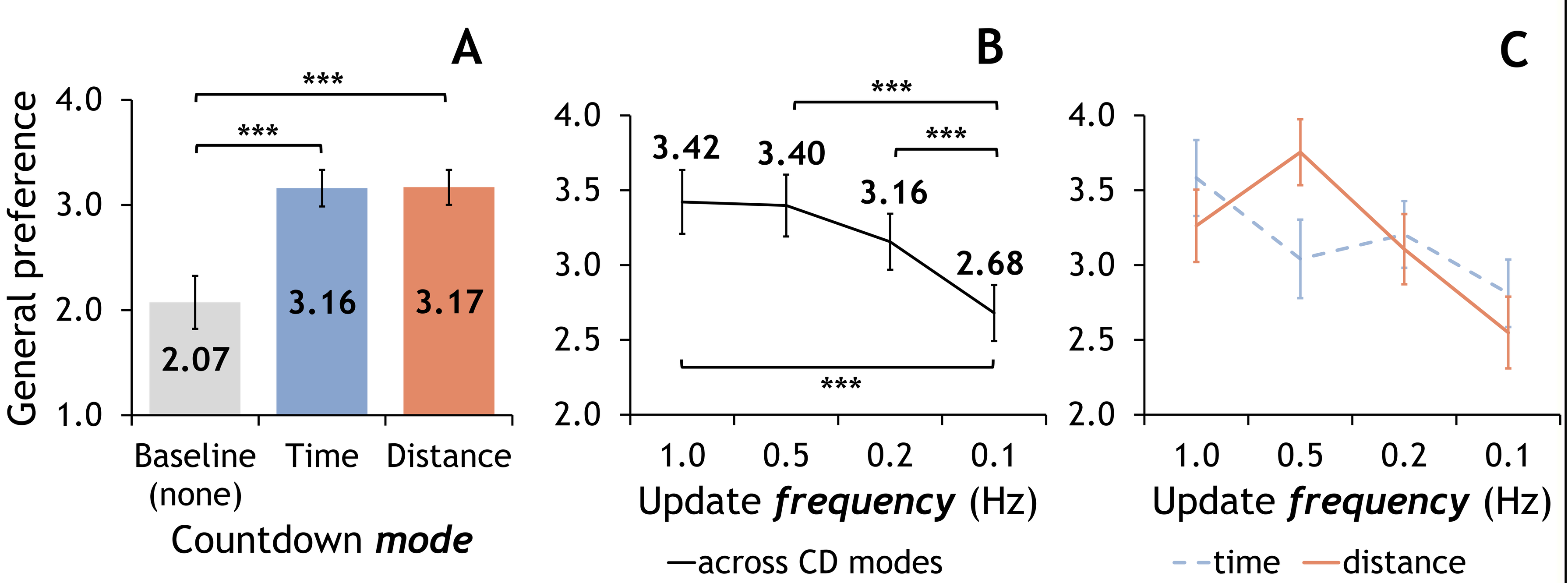

Figure 1. General preference of the countdown displays (from 0 = "fail" to 5 = "very good") depending on **A)** CDD mode, **B)** update frequency, and **C)** their interaction. Error bars: 95%-KI, ***p < .001

Conclusion

- Participants understood the information provided by CDDs on upcoming maneuvers of the HAS
- Findings suggest, that the use of CDDs at the rear of HASs as external HMI can increase the transparency of the situation and thus improve situation awareness of following traffic
- The application of both modes (i.e., time or distance) seems appropriate, further investigations about suitable update frequencies are recommended, e.g. to avoid information overload in traffic

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