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Driver perspectives of open and tunnel expressways

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ABSTRACT

Urban road tunnels are becoming more extensive due to land scarcity in city areas, and accident rates in these tunnels are comparatively lower than those on open roads. This study examines drivers' perspectives of open and tunnel expressways for 114 active drivers in Singapore using the free association technique. The driver perspectives of open and tunnel expressways were found to be different using *t*-tests on the frequency of associations to each category, and through multidimensional scaling analysis. Drivers perceive speed, traffic condition, and scenery to be most prevalent for open expressways; while lighting, enforcement, and safety are most prevalent for tunnel expressways. Road qualities important to the driver are identified in this study and the findings are discussed. Analysis of response valence reveals that tunnels are generally perceived less positively as compared to open expressways, and ANOVA found that frequent tunnel users do not perceive tunnel expressways more positively than infrequent users. The response valence is also found to correlate well with the reported quality of experience in each environment. The differences in driver perspectives may help explain differences in driver behaviour. Findings from this study also provide insight to road planners in meeting quality needs of drivers.

1. Introduction

One of the many challenges faced by the world today is urban sustainability. As megacities continue to expand and develop, their growth is constrained by limited land space. To overcome this limitation, cities are beginning to utilise underground space, especially for transport uses.

Several studies (Ronka, Ritola, & Rauhala, 1998; Sahlström, 1990; Sterling, 1997) acknowledge the use of underground transport solutions, which frees up surface land for other purposes; protects the environment from noise and pollution; and reduces traffic in important city streets. As underground road systems (URS) become more extensive, drivers spend a greater portion of their driving time in road tunnels and it will be increasingly important to ensure that drivers are able to drive comfortably and safely in the tunnels.

Studies have shown that driver behaviour and perception vary in different situations such as handling secondary tasks (Briggs, Hole, & Land, 2011; Metz, Schomig, & Kruger, 2011; Recarte & Nunes, 2003), intersections (Dukic & Broberg, 2011; Werneke & Vollrath, 2012), different road widths (Antonson, Ahlström, Wiklund, Blomqvist, & Mårdh, 2013; Dijksterhuis, Brookhuis, & De Waard, 2011), different road complexities (Cantin, Lavalliere, Simoneau, & Teasdale, 2009; Stinchcombe & Gagnon, 2010), different times of the day (Chipman & Jin, 2009), different luminance levels (Hogema, Veltman, & Hof, 2005), different weather (Konstantopoulos, Chapman, & Crundall, 2010), and even slight changes in the surrounding landscape including trees (Antonson, Mårdh, Wiklund, & Blomqvist, 2009) and crash barriers (Antonson et al., 2013). It can hence be expected that an entirely different road environment such as urban road tunnels will also result in different driver behaviour. However, there is limited knowledge on how perception and behaviour is different in urban road tunnels.

In terms of safety, studies have shown that traffic accident rates in road tunnels are generally lower than those on open roads (Amundsen & Ranes, 2000; Lemke, 2000; Ma, Shao, & Zhang, 2009). This implies that drivers exhibit an overall safer driving behaviour in road tunnels, thus resulting in fewer accidents.

With regard to road tunnel users, several researchers attempted to study motorist behaviour through channels such as roadside surveys (Amundsen, 1994; Serrano & Blennemann, 1992) and questionnaires (Arias, López, Fernández, Martínez-Rubio, & Magallares, 2008). These studies generally point towards negative

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perceptions of the tunnels. Novel approaches, with the aid of improved technology, include those that study both driver and driving behaviour in road tunnels using instrumented vehicles (He, Chen, Wang, & Shi, 2010; Zhao, Jiang, & Hu, 2011; Zhao & Liu, 2011) and driving simulators (Hirata, Mahara, & Yai, 2006; Kircher & Lundkvist, 2011; Mühlberger, Bulthoff, Wiedemann, & Pauli, 2007; Mühlberger, Wieser, & Pauli, 2008; Shimojo, Takagi, & Onuma, 1995; Törnros, 1998). Yeung (2013) investigated the car-following patterns in urban tunnel expressway and found that drivers maintained larger gaps in the tunnels, as compared to open expressways, controlled for speed. This reflects a more conservative driving behaviour exhibited in tunnels.

According to environment-behaviour theories, behaviour is a manifestation of the individual's perspectives and perceptions of the environment. The theory of planned behaviour (Ajzen, 2005; Steg & Nordlund, 2013) indicates that behaviour is indirectly modulated through intention by personal norms, attitude, subjective norms, and perceived behavioural control.

In order to have a holistic understanding of driver behaviour, it is essential to investigate the effects of the road tunnel environment on driver perspectives and quality needs, and how they may affect drivers and driving behaviour.

Conventional perception surveys have usually involved the use of structured questionnaires and guided options. For instance, statements like "I feel safe driving in the tunnels" are usually followed by a five- or seven-point scaled option ranging from "Strongly Disagree" to "Strongly Agree". In such questions, the category (feelings of safety) is stated upfront and respondents are only required to express their valence (level of agreeableness) towards the category. Although this type of questions results in structured and objective responses which make the analysis procedure easier for the analyst, it does not take into consideration how strongly respondents associate to these categories or how strongly these categories are interconnected. The effectiveness of using scales is undermined when the predetermined categories do not reflect the underlying prevalence of each category. However, attempting to cover every plausible category would result in lengthy questionnaires and complicated analyses.

As such, the free association technique was used in this study. The technique is unrestrictive on the drivers and will allow drivers to freely draw thoughts and recall relevant elements regarding the expressways. The researcher is able to measure the strength of the association between a given domain and the categories associated with it. The list of categories can also be used to portray the current perspective of the domain (Granié & Papafava, 2011). The responses provided by the respondent will be most strongly associated to the given domain and the most frequently associated categories can then be inferred to be the most prevalent domain characteristics to the respondents.

The technique and its variant forms: free listing and word association, have been used in various fields such as food quality (Ares & Deliza, 2010; Guerrero et al., 2010; Hough & Ferraris, 2010; Rozin, Kurzer, & Cohen, 2002), social science (Gaymard, 2006), and transport-related research (Granié & Papafava, 2011).

The study is conducted in Singapore and its main objective of this study is to investigate driver perspectives of both open and tunnel expressways. Singapore is highly motorised island-state with a vehicle density of 106 vehicles per lane km. Figs. 1 and 2 show snapshots of typical open and tunnel expressways in Singapore, respectively. There are currently 161 km of expressways in Singapore, of which around 11 km are underground tunnel sections; 0.3 km semi-open section; and the remaining open road sections.

In this study, three hypotheses are being tested. H1: drivers perceive open and tunnel expressways differently. This is expected to be true since driving behaviour in tunnels is found to be more conservative and behaviour is modulated by perspectives and perceptions.

Fig. 1. Typical open expressway in Singapore. Source: www.maps.google.com.sg.

H2: drivers who use tunnel expressways more frequently perceive the tunnels more positively than infrequent users due to increased familiarity. This will be of interest to road planners in understanding whether initial negative impressions of roads tunnels can be offset by tunnel usage frequency.

H3: drivers who feel more positively (or negatively) towards a particular domain will tend to provide a greater number of positive (or negative) responses for that domain. This implies that the free association technique serves as a valid measurement of driver attitudes.

The first two hypotheses directly relate to the main focus of the paper; while H3 is additional in understanding the usefulness of the free association technique.

2. Methodology

2.1. Questionnaire and dissemination

The two domains in this study are the open and tunnel expressways, and the categorical associations are to portray the most prevalent roadway qualities in the drivers' perspective. Semi-open expressways are not considered due to the lack of substantial presence in the Singapore road network.

Each questionnaire consists of three sections. Section I asks the subject to imagine driving on an open expressway and list the first five words, thoughts, feelings or expressions that come to mind. Similarly, Section II requires the subject to imagine driving in a tunnel expressway and list the first five responses that come to

Fig. 2. Typical tunnel expressway in Singapore.

Table 1
Distribution of respondents by gender, age, and tunnel usage frequency.

Tunnel usage[a]	Male age			Female age			Total
	18–30	31–45	46–60	18–30	31–45	46–60	
Frequent	15	8	3	5	3	1	35 (30.7%)
Occasional	19	7	3	8	2	1	40 (35.1%)
Rare	13	6	7	6	4	3	39 (34.2%)
Total	47 (58.0%)	21 (25.9%)	13 (16.0%)	19 (57.6%)	9 (27.3%)	5 (15.2%)	114 (100%)

[a] Frequent = Several times a week or more; Occasional = Several times a month; Seldom = Several times a year or less.

mind. However, it was not compulsory for subjects to list a total of five responses for each of Sections I and II.

Section III asks for the respondent's age group, gender, and driving experience, frequency of road tunnel usage. Different from the approach used by Granié & Papafava (2011), where subjects were divided into two groups and each group provided responses to a single stimulus, this study requires all subjects to provide responses to both stimuli of open and tunnel expressways. Also, to test the third hypothesis of the study, respondents are asked to rate on a scale of one (dislike) to five (like) their overall experience in each of the road environments.

The questionnaire was disseminated via three modes, in sequential order: online open participation (participants mostly aged 18–30), mail-back forms with URL link for online version (placed on the windshields of parked cars in various car-parks, 4.5% mail-back response rate, participants mostly aged 18–45), and face-to-face interviews (conducted near car-parks, aimed at participants aged 31–60, with near-complete response rate). In all three modes, especially face-to-face interviews, it was ensured that the respondents were not provided with any form of guidance in their responses. Three modes are used in order to engage sufficient respondents from each age group.

To minimise order effects, respondents were randomly assigned questionnaires which presented sections in the order of either I-II-III or II-I-III, in an unsystematic manner.

2.2. Subjects

Since free association relies on a memory recall function based on the stimuli presented to the subject, only complete questionnaires filled in by active drivers (identified through the respondent particulars) are considered in this study.

After filtering the questionnaires, there are a total of 114 questionnaires completed by active drivers. Table 1 shows the distribution of respondents by gender, age group, and tunnel usage frequency. No significant difference was found in the distribution of respondents between males and females, $\chi^2 = 1.658$ $df = 8$, $p = 0.9898$.

2.3. Responses

A combined total of 1107 responses are collected from both Sections I (551) and II (556), yielding an average of 9.884 responses per subject (4.92 for Section I, 4.96 for Section II). Also, out of the 114 questionnaires, 55 (47.3%) presented Section I before Section II; while the other 59 (52.7%) presented Section II first. These responses are coded into categories for analyses. First, the mean frequencies of associations to each domain are compared using paired two-tail t-tests, for each category. Holm-Bonferroni corrections for multiple comparisons are made to control the family-wise error rate at $\alpha = 0.05$.

Second, multidimensional scaling analysis was performed to map the categories and their inter-correlations onto a two-dimensional plot.

Third, one-way ANOVA was performed on the response valences to investigate the effects of tunnel usage frequency on the tendency to provide positive or negative responses. In addition, the relationship between the respondent valences and self-reported ratings for each expressway type was investigated to find out if response valences could indeed be used to understand the respondents' attitude towards each domain.

Table 2
Definitions and examples of coded categories of associations.

Category	Definition	Common words
SPEED	Responses related to speed	Fast, slow, speed
ROAD	Responses related to the physical road pavement	Smooth, bumpy, lanes, straight
OTHER MOTORISTS	Terms related to motorists other than the subject	Reckless drivers, cars, inconsiderate drivers, road-hog
TRAFFIC CONDITION	Words describing the state of traffic	Congestion, jam, cruising, too many cars
SAFETY	Words related to the act or state of safety	Safe, dangerous, accident, caution
EMOTION	Feelings or expressions that describe an emotion	Happy, uncertain, claustrophobic, relaxed
PURPOSE	Expressions related to the purpose of the trip	Going to work, will I be late
COST	Terms that relate to the costs of travel	Electronic road pricing (ERP), petrol, expensive
SCENERY	Items in peripherals & words describing them	Trees, wall, greenery, orangey
ENFORCEMENT	Words related to traffic enforcement	Traffic police, speed cameras, speed limit
SPACE	Words related to spatial dimensions	Long, wide, narrow, width, enclosed, open
TEMPERATURE	Adjectives for temperature	Hot, cooler
LIGHT	Words related to lighting	Lighting, dark, brightness, headlight
CONTROL	Includes manoeuvres and vehicular control	Overtake, slow down, accelerate, lane change
SIGNAGE	Words related to road signs & traffic information	Signage, EMAS (traffic information), blocked signs
WEATHER	Includes weather effects	Raining, sheltered, flooding
SIGHT DISTANCE	Responses related to the ability to see	Visibility, unobstructed, clearer view
RECEPTION	Words related to radio or GPS	Radio, GPS, reception
SOUND	Includes sounds & their adjectives	Noisy, music, sound, echo
EXITS	Responses containing "exit"	Exits, looking for exits, which exit to use
AIR	Words related to air quality	Ventilation, smoky, fresh air
OTHERS	Uncommon words not in any other categories	Food, wheel

Table 3
Mean frequencies of response association (with standard deviation) for each category.

Category	Mean frequencies of response association (S.D.)		T value	Holm-Bonferroni corrected p-value
	Section I - Open	Section II - Tunnel		
LIGHT	0.105 (0.308)	0.868 (0.685)	-11.94	<0.001
TRAFFIC CONDITION	0.649 (0.665)	0.237 (0.485)	5.96	<0.001
RECEPTION	0.026 (0.161)	0.159 (0.368)	-3.62	0.008
SOUND	0.018 (0.132)	0.132 (0.365)	-3.29	0.024
EXITS	0.018 (0.132)	0.140 (0.373)	-3.26	0.025
COST	0.167 (0.419)	0.035 (0.185)	3.26	0.024
OTHER MOTORISTS	0.368 (0.812)	0.167 (0.459)	2.9	n.s.
SCENERY	0.368 (0.655)	0.167 (0.478)	2.81	n.s.
SPEED	0.579 (0.563)	0.412 (0.529)	2.58	n.s.
SAFETY	0.377 (0.586)	0.544 (0.706)	-2.23	n.s.
ENFORCEMENT	0.272 (0.599)	0.421 (0.677)	-2.18	n.s.
AIR	0.026 (0.209)	0.079 (0.302)	-1.92	n.s.
SIGHT DISTANCE	0.079 (0.380)	0.018 (0.132)	1.62	n.s.
EMOTION	0.605 (0.908)	0.465 (0.719)	1.59	n.s.
PURPOSE	0.149 (0.426)	0.088 (0.314)	1.41	n.s.
TEMPERATURE	0.018 (0.132)	0.044 (0.206)	-1.14	n.s.
ROAD	0.289 (0.606)	0.228 (0.516)	1.12	n.s.
WEATHER	0.088 (0.314)	0.053 (0.224)	1.07	n.s.
CONTROL	0.237 (0.599)	0.219 (0.545)	0.39	n.s.
SIGNAGE	0.105 (0.361)	0.114 (0.346)	-0.24	n.s.
SPACE	0.237 (0.503)	0.246 (0.525)	-0.18	n.s.

2.4. Encoding

The responses from Sections I and II are encoded into their respective categories and valences. Similar to the free association study on food by Rozin et al. (2002), the categories are not determined before data collection. Instead, the categories are generated using the data collected. For each response, it was determined which existing category it would best belong to. If none of the existing categories sufficiently describes the response, a new category will be generated by the first encoder. Thus, the categories generated by this approach are, in principle, mutually exclusive.

Based on the responses from both Sections I and II for all subjects, 22 categories were generated. The individual categories, along with their definitions and some common responses associated with them are listed in Table 2. It should be noted that in rare cases where responses were considered by the encoder to be associated to more than one category, multiple associations were coded for those responses.

Also, the response valences were considered. Each response could either be a positive, neutral, or negative association to the categories. For instance, the response "traffic congestion" will be assigned a negative valence in the category *TRAFFIC CONDITION*. On the other hand, "cruising" will be assigned a positive valence in the same category. Neutral valences are assigned to responses such as "speed", "safety", "lights", and "weather", which are usually nouns which do not offer any description to the associated category.

Each positive association is given a valence of +1, while each negative association is given a valence of −1; and neutral associations are given a valence of 0. The categorical valences are added up to obtain the overall valences for individual respondents corresponding to each of the two road environments. The overall categorical valence measures the overall tendency of the respondent to give positive or negative responses.

As in the study by Granié & Papafava (2011), after all the responses were encoded by the first encoder, a second encoder encoded 25% of the data (277 responses) selected at random. The second encoder categorised the responses using the definitions listed in Table 2. An interrater reliability analysis using the Kappa statistic was performed to determine consistency among the encoders. The reliability analysis was performed twice – once for the categorical associations; and once for the response valences. For the categorical associations, it was found that Kappa = 0.803, $p < 0.001$. For the response valence, it was found that Kappa = 0.854, $p < 0.001$. The Kappa values of greater than 0.80 indicate good interrater reliability.

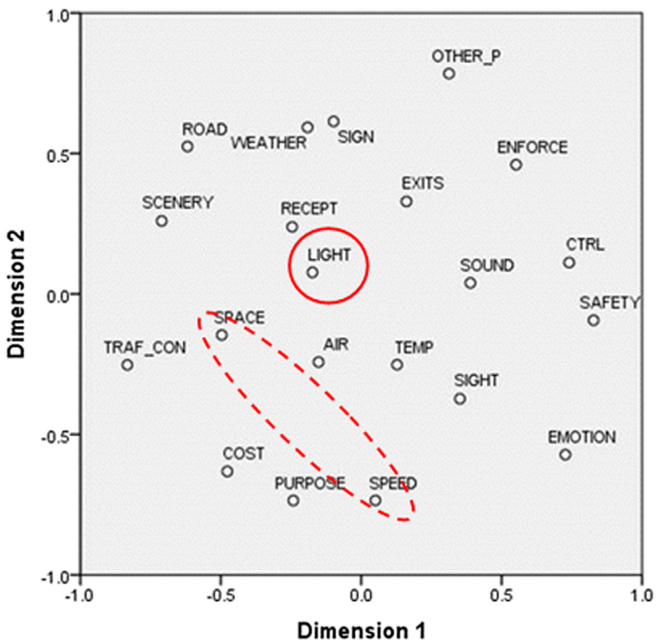

Fig. 3. Multidimensional scaling analysis on coded categories for open expressways.

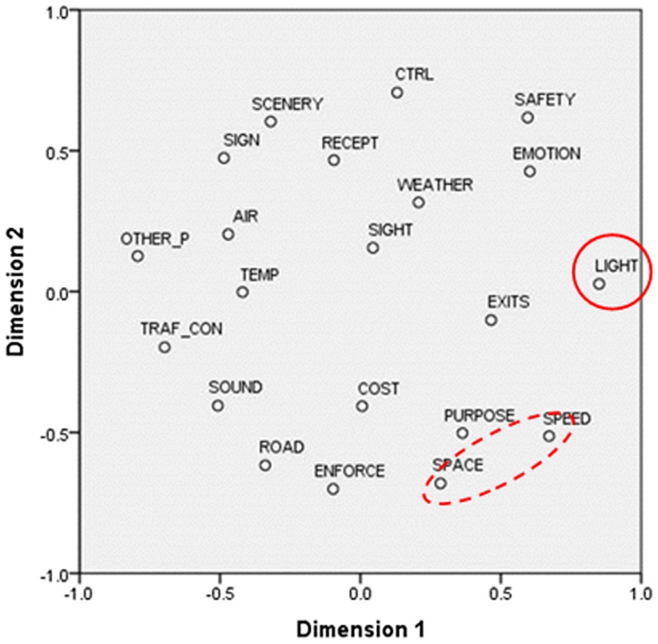

Fig. 4. Multidimensional scaling analysis on coded categories for tunnel expressways.

3. Results

3.1. Frequency of categorical association

From the 1107 subject responses, 1112 categorical associations were identified. The mean frequencies of response association for each category, for both Sections I and II, are shown in Table 3. The mean frequency of response association is the average number of responses, which is associated to a particular category, generated by a respondent.

The results indicate that, for open expressways, the most frequently (more than 30%) associated categories are (in descending order) *TRAFFIC CONDITION*, *EMOTION*, *SPEED*, *SAFETY*, *OTHER MOTORISTS*, and *SCENERY*. For tunnel expressways, the most frequently associated categories are (in descending order) *LIGHT*, *SAFETY*, *EMOTION*, *ENFORCEMENT*, and *SPEED*. This suggests that most prevalent roadway qualities to the drivers for open expressways are different from that for tunnel expressways. On an open expressway, drivers perceive traffic conditions and flow speeds to be the most prevalent elements but in a tunnel expressway, lighting conditions and tunnel safety take over.

Next, *t*-tests are performed to compare the means for each category between open and tunnel expressways. The results reveal that associations to *SPEED, OTHER MOTORISTS, TRAFFIC CONDITION, COST,* and *SCENERY* were statistically more frequent in open expressways (absolute T values greater than 1.96). On the other hand, *SAFETY, LIGHT, RECEPTION, SOUND,* and *EXITS* were statistically more frequent in tunnel expressways. However, after Holm-Bonferroni corrections for multiple comparisons, statistical significance was only found for *LIGHT, TRAFFIC CONDITION, RECEPTION, SOUND, EXITS*, and *COST.*

3.2. Multidimensional scaling

Multidimensional scaling analysis was performed to model the driver perspectives of open and tunnel expressways. The inter-correlation matrix served as a pseudo-similarity matrix for multi-dimensional scaling, excluding the category *OTHERS*. The model shows the relative prevalence of each of category on a two-dimensional space. The two-dimensional model is adopted according to Parsimony's Law. Furthermore, the normalised raw stress value is low (Open 0.10; Tunnel 0.11), and the Dispersion Accounted For (Open 0.90; Tunnel 0.89) and Tucker's Coefficient of Congruence (Open 0.95; Tunnel 0.94) are close to 1.

Figs. 3 and 4 illustrate the two-dimensional models corresponding to driver perspectives of open expressways and tunnel expressways, respectively. Both maps show the more prevalent categories being positioned nearer to the perimeter. It should be noted that the dimensions on both maps are arbitrary, and may not be the same. The maps reflect the relative distance of one category to another, for the two different road environments. Note: *OTHER_P* in the maps refers to *OTHER MOTORISTS*, the rest are self-explanatory.

As observed in Figs. 3 and 4, the driver perspectives of open and tunnel expressways are rather different. For instance, the position of *LIGHT* (marked by solid circle) is in the middle for open expressways, while it is at the right-most for tunnel expressways, highlighting the increased prevalence of *LIGHT* in the tunnels. Inter-categorical distances are also different. For instance, the gap between *SPEED* and *SPACE* (marked by dashed ellipse) is shorter for tunnel expressways, i.e. the two categories are more likely to be associated with each other in tunnels.

3.3. Effect of tunnel usage frequency on categorical valences

The next part of the analyses took into consideration the categorical valences. The mean valence for open expressway is 0.351 (*s.d.* 2.51), and −1.149 (*s.d.* 2.13) for tunnel expressway. Drivers had higher tendencies to provide negative responses for tunnel expressway, and this suggests that tunnel expressways are not as popular as open expressways. Table 4 shows the mean counts (with standard deviation) disaggregated by gender and tunnel usage frequency. One-way ANOVA is performed on the mean valence and no significant effects of gender and tunnel usage frequency are found.

3.4. Responses valences as attitude indicators

The respondents also rated their experience in open and tunnel expressways. On a scale of one (dislike) to five (like), the mean

Table 4
Disaggregated mean positive and negative associations (with standard deviation).

		Open		Tunnel	
		Positive	Negative	Positive	Negative
Gender	Female	2.12 (1.63)	1.30 (1.53)	0.76 (1.12)	2.00 (1.37)
	Male	1.44 (1.40)	1.28 (1.37)	0.73 (1.10)	1.84 (1.54)
Tunnel usage (Several times a …)	… week or more	1.66 (1.71)	1.49 (1.46)	0.77 (1.11)	2.29 (1.60)
	… month	1.55 (1.26)	1.40 (1.57)	0.75 (1.19)	1.70 (1.49)
	… year or less	1.72 (1.54)	1.00 (1.17)	0.69 (1.00)	1.72 (1.34)

rating is 3.73 (*s.d.* 0.989) for open expressway and 3.28 (*s.d.* 1.043) for tunnel expressway. The difference is found to be statistically significant ($t = 3.519$, $df = 113$, $p = 0.001$). ANOVA found no significant effects of gender or tunnel usage frequency.

Fig. 5 shows a plot of the mean respondent valences for each rating. It is observed that there is an observed linear relationship between the valences and the ratings, with high R^2 values. Respondents who like that particular road environment were more likely to provide more positive associations (or less negative associations). Also, it would appear that drivers have lower expectations for tunnel expressways, as shown by the smaller slope gradient. Evidently, the overall response valence of a driver correlates to the driver's attitude towards the domain, and serves as a valid measurement of driver attitudes.

4. Discussion

The study set out to find out 1) whether drivers perceived open expressways differently from tunnel expressways; and 2) whether frequent tunnel users perceived tunnel expressways more positively than infrequent users. The free association technique was used to collect information for this study. In addition, the study aims to find out 3) whether there is any relationship between the categorical valences and the reported overall experiences in each domain.

4.1. Driver perspectives of open and tunnel expressways

The results show that driver perspectives for open expressways and tunnel expressways are indeed different to some extent. After coding the responses into their respective categories, the categorical associations found that the most prevalent items to the drivers differ for open and tunnel expressways, as shown in Table 3. Driver perspective models obtained through multidimensional scaling also illustrate the differences.

Prevalent roadway qualities in open expressways are more traffic-oriented and relate directly to the inter-vehicular interactions (*SPEED*, *TRAFFIC CONDITION*, *SCENERY*, and *OTHER MOTORISTS*). For tunnels, the prevalent qualities are more self-oriented and relate directly to the subjects' individual interaction with the road environment (*ENFORCEMENT*, *LIGHT*, and *SPEED*). The most strongly associated qualities are found to be clearly different for the two expressway types. Multidimensional scaling analysis is used to model driver perspective using the inter-correlation of the categorical associations. The models show the perceptual structure of each road environment, with the more prevalent items nearer to the perimeter. Visual comparisons will show how each roadway characteristic varies in various environments in terms of prevalence (distance from centre of centroid) and relation to other characteristics (relative position of characteristics).

As shown in Table 3, associations to six categories were found to be significantly different between the two road environments.

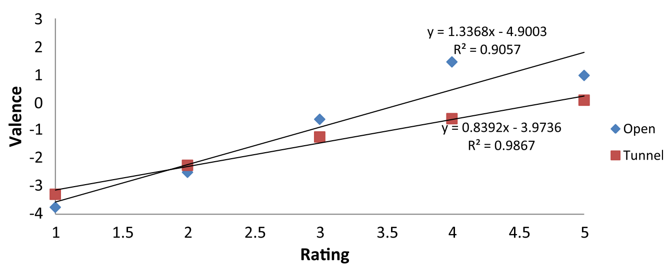

Fig. 5. Mean respondent valence against rating for open and tunnel expressways.

Decreased associations to *TRAFFIC CONDITION* for tunnel expressways are likely due to the traffic management policies resulting in low congestion rates in the tunnels. Thus, traffic conditions become seemingly 'irrelevant' in the tunnels.

Meanwhile decreased associations to *COSTS* are most likely due to the absence of Electronic Road Pricing (ERP) gantries in the tunnels. In Singapore, ERP gantries are erected at roads leading to high congestion areas. During certain hours of the day, ERP gantries are activated and vehicles passing through these gantries will have the toll fees electronically deducted without having to stop.

There is an increase in associations to *LIGHT* in tunnel expressways. Drivers perceive tunnels as darker environments without natural lighting, and hence acknowledge the importance of lighting in tunnels, complemented by the road signs that advise drivers to switch on headlights when driving in the tunnels. Since driving depends on vision, it is likely for drivers to feel that their visual performance is impaired in the tunnels due to the lower luminance levels. In fact, *LIGHT* was expected to be the most prevalent road tunnel quality.

Also, increased associations to *EXITS* in tunnel expressways could be related to the absence of unique and distinctive landmarks in the tunnel. Studies have shown that landmarks are essential in efficient way-finding and environmental cognition (Burnett, 2000; May & Ross, 2006; Ross, May, & Grimsley, 2004). When landmarks are used in navigational tasks, fewer directional errors are made and navigation performance is improved (Ishikawa, Fujiwara, Imai, & Okabe, 2008; Roger, Bonnardel, & Le Bigot, 2011). In the absence of navigational landmarks in the tunnels, geographic knowledge is not facilitated (Evans, Skorpanich, Gärling, Bryant, & Bresolin, 1984) and drivers may find it difficult to identify locations. As a result they are constantly looking out for their desired exits.

Alternatively, some drivers may be claustrophobic and wish to exit the tunnels as soon as possible. Marec (1996) mentioned that when there is an accident in road tunnels, drivers naturally prefer to escape through the tunnels instead of going into the 'clearly indicated shelters provided inside the tunnel'. This suggests that wanting to exit the tunnels is a safety-seeking behaviour. Further research is required to investigate claustrophobic behaviour in tunnels, so as to determine ways to mitigate claustrophobia-related problems.

Increased associations to *RECEPTION* and *SOUND* in tunnels are likely due to the tunnel infrastructure blocking out GPS reception and retaining sounds within, and also the instructions asking drivers to switch on their radios when entering the tunnel.

Other notable differences, though not shown to be significant, include increased associations to *ENFORCEMENT* and *SAFETY* in the tunnels. Speed limits in the tunnels are generally lower than open expressways in Singapore, and the speed cameras are hard to spot within the tunnels. As a result drivers are more constrained in driving within the speed limit and hence greater associations to *ENFORCEMENT*.

Increased associations to *SAFETY* may be due to feelings of insecurity and riskiness inside the tunnels, possibly attributed to elements of claustrophobia. Enclosed spaces, entrapment, darkness and a lower level of perceived control are said to induce fear and avoidance of underground spaces (Carmody, Huet, & Sterling, 1994; Ringstad, 1994). Other fears may stem from feelings of disorientation (Goel, Singh, & Zhao, 2012). This fear in turn translates to a "subjective risk" experienced by the drivers, affecting driver behaviour in a conservative manner (Näätänen & Summala, 1976). This is consistent with findings of Yeung (2013), where drivers are found to maintain larger gaps in tunnels.

Judging by the relative prevalence of the roadway qualities in the two expressway types, it is interesting to note that *TRAFFIC CONDITIONS* and *SPEED* are placed higher than *SAFETY* and

ENFORCEMENT on open expressways; while *SAFETY* and *ENFORCEMENT* are placed above *SPEED* and *TRAFFIC CONDITIONS* in tunnel expressways.

Capacity and safety are known to be two conflicting aspects in traffic management – the enhancement of a single aspect would mean the compromise of the other. Since drivers perceive capacity-related qualities to be more prevalent on the open expressways, it would be intuitive to say drivers in general drive faster and in a more aggressive manner on open expressways, in order to reduce travel time. On the other hand, since safety-related qualities are strongly associated with tunnel expressways, drivers in general would drive slower and be more compliant with traffic laws in the tunnels, in order to enhance road safety.

4.2. Categorical valences

Considering the categorical valences, it is evident that most drivers perceived road tunnels with more negative associations and fewer positive associations than open expressways. This is consistent with the findings on Arias et al. (2008), who found that tunnels induce unpleasant feelings and greater levels of perceived risk than open roads. In the current study, more associations (mostly negative) to *SAFETY* were also found for tunnel expressways. Furthermore, self-reported ratings reveal that open expressways are preferred over tunnel expressways.

The findings from Antonson et al. (2009) suggest that driving speeds decrease, lateral positioning tends towards the road centre, and emotional stress increases, as the landscape settings deviate away from open landscapes in terms of "openness". Road tunnels would then represent an extreme landscape setting where "openness" is at the minimum. Yeung (2013) found that drivers reported greater mental demand, effort, and temporal demand in the tunnel expressway, after performing the same tasks in both open and tunnel expressways. This exemplifies a difference in attitudes towards road tunnels.

The findings are consistent with the evolutionary theories on landscape preferences, especially the biophilia hypothesis, which states that humans have innate tendencies to seek contact with animals, plants, and natural landscapes. Presence of natural elements in the urban setting is said to help reduce stress and mental fatigue (van den Berg, Hartig, & Staats, 2007). Also, drivers have reported higher frustration tolerance in nature-dominated roads compared to completely built roads (Cackowski & Nasar, 2003).

4.3. Effects of tunnel usage frequency

It was hypothesised that drivers who use tunnels more frequently would perceive tunnels more positively due to the increased familiarity. To test this hypothesis, ANOVAs are performed for categorical valances and respondent ratings.

It was found that tunnel usage frequency had no significant effects on the valence of the association and the ratings. Despite being more familiar with the tunnels, frequent tunnel users did not perceive tunnels more positively than infrequent users. This means that roadway perspectives, in terms of categorical associations and valences, are consistent across various groups of tunnel users. Initial impressions of the tunnel environment are retained over time and do not improve.

4.4. Implications of the findings

There are several practical implications of the findings obtained in this study. First, the difference in prevalent items implies that drivers perceive road tunnels differently from open roads. These differences may modulate driving behaviour.

Evidently, this study reveals that drivers perceive illuminating elements more importantly in the tunnels. Lighting in tunnels thus plays a crucial role affecting drivers, through visual influences. Since safe driving depends primarily on the driver's visual perception and psychomotor skills, it is reasonable to argue that any factors affecting the driver's vision will have impacts on road safety.

Studies involving visual scanning patterns (Crundall & Underwood, 2011; Harbluk, Noy, Trbovich, & Eizenman, 2007; Konstantopoulos et al., 2010) generally agree that increased road scene scanning has a protective effect on driver safety. Scanning increases the likelihood of detecting hazards early and shorter reaction times. Hence, the influences of lighting on visual attention should be further investigated.

Second, it is also discussed that road tunnel driving is likely to be more stressful than open road driving. Stress is associated with increased cognitive loading, which has a negative effect on road safety (Cantin et al., 2009; Harbluk et al., 2007; Lee, Lee, & Boyle, 2007; Recarte & Nunes, 2002; Stinchcombe & Gagnon, 2010). Most of these studies show that with high mental workload, driving performance deteriorates – reaction times increase, visual detection is impaired, road scene scanning is reduced, and the number of hard braking events increases. This implies that road safety in road tunnels may be compromised. Thus, interior design concepts for tunnels need to be explored for optimal concepts that induce minimal stress in the drivers.

Interestingly, studies have also found that accident rates in road tunnels are generally lower than those on open roads (Amundsen & Ranes, 2000; Ma et al., 2009; Yeung & Wong, 2013), possibly a result of increased vigilance due to the increased subjective risk experienced by drivers, a compensatory behaviour.

Also, the results reveal that frequent tunnel users are not more receptive towards the tunnels than infrequent users. Tunnel users generally responded with significantly more negative than positive associations to tunnels. This finding reinforces the importance of the tunnel architecture and interior design to alleviate negative associations to the tunnel infrastructure. This is especially important for city planners to mould liveable cities and meet the quality needs of the people. This study has successfully identified roadway qualities in open and tunnel expressways that are prevalent to drivers.

4.5. Free association as a valid measurement of driver attitudes

The free association technique allows the analysis to be open to categories which are not predetermined. It is essentially a user-centric approach which does not limit respondents to providing feedback based on a predetermined scope. Furthermore, additional psychological constructs or situational models relative to traffic safety may also be found in the process. This study has demonstrated that driver attitudes can be understood through the response valences.

This approach may also be applied to various road settings such as intersections, arterials roads, etc., which can help identify important road elements or roadway qualities that road users perceive as important for the particular road setting so that enhancements can be made to improve the driving experience and road safety.

4.6. Interpretation of analyses

Response biases may be observed in online open participation and mail-back questionnaires, where the respondents mostly belonged to the two younger groups of the three predefined age groups. However, it was not possible to ascertain whether nonrespondents were older persons, since information on the age distribution of active drivers is unavailable.

In addition, it was not possible to improve the response rates for mail-back questionnaires through reminders, in the absence of driver addresses. As a result, face-to-face interviews had to be conducted in order to engage older respondents. However, the overall proportion of older drivers in the 46–60 years age group remains relatively low (~15%).

Nonetheless, the interpretations of the analyses are unlikely to be affected since age is not considered as a factor. In a free-listing study by Schrauf and Sanchez (2010), it was found that differences in production between old and young seemed to disappear when items were limited to those mentioned by at least two people or more. They noted that this applies to cases where different age groups have the same relative familiarity with the domains of interest (as was the case in this study).

It is thus possible for the results obtained in this study to be generalised to all drivers, on the presumption that age-related differences in free association are negligible. However, since free association is heavily dependent on the respondent's direct experience in the particular domain, it should be noted that the results of this study may not generalise to freeways in other regions, where driving cultures and practices greatly differ. Furthermore, extensive research has shown that there are differences in driver attitudes across different countries and culture (Lajunen, Özkan, Chliaoutakis, Parker, & Summala, 2006; Nordfjærn, Jrgensen, & Rundmo, 2011; Özkan, Lajunen, Chliaoutakis, Parker, & Summala, 2006; Warner, Ozkan, & Lajunen, 2009; Warner, Ozkan, Lajunen, & Tzamalouka, 2011). This means that although we can expect the prevalent categories to be largely similar across regions, the overall valences may vary.

5. Conclusion

This study attempted to investigate the differences in driver perspectives of open and tunnel expressways, in terms of associations to various roadway qualities, and the valence of these associations. The free association technique has, together with *t*-test and ANOVA, been proven to be useful when investigating the roadway qualities prevalent to drivers. The results are based on the most accessible memory of the road environments and give insight into how driver perspectives are shaped.

With regard to the three hypotheses set out, this study has managed to show insightful results: 1) as expected, drivers indeed perceived tunnel expressways in ways different from the open expressways – self-oriented items are found to be more prevalent in the tunnel environment; 2) drivers had significantly more negative associations to the tunnel environment as compared to the open expressways, and unexpectedly, drivers who use the tunnels more frequently did not perceive the tunnels more positively compared to less frequent users; and 3) as expected, drivers who reported better experiences tend to have more positive associations and the reverse is also true – drivers who reported poorer experiences tend to have more negative associations.

The results can serve as the basis for further research in road tunnel design. The various roadway qualities identified to be prevalent to the drivers can be set as variables to determine the optimal design parameters, where road safety and quality of driving are optimised. For instance, this study found that lighting, feelings of safety, and the type of enforcement/surveillance systems are important to the drivers and are the most likely factors to modulate driver behaviour in the road tunnel environment and the quality of driving.

The varying driver perspectives is likely to lead to different driving behaviours in the two road environments, which might explain the differences in driving behaviour and accident rates between the two road environments. Increased associations to self-oriented categories and increased negative associations may imply that drivers perceive the tunnels as hostile environments with higher levels of risk. As a result, drivers adopt safer driving behaviours, such as maintaining larger gaps and being more vigilant, as a form of risk compensation. On a macroscopic level, this translates to overall lower accident rates in tunnels.

Although evidence shows that current road safety levels in tunnels are generally higher, there is good reason to research ways to improve the current standards. Lemke (2000) pointed out that "as long as tunnels form only a small part of the roadway network, drivers tend to drive more carefully in tunnels." As more cities begin to utilise urban underground road systems, it is increasingly important to understand how road users perceive these new environments and how their behaviour may be affected.

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