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Relation between riding pleasure and vehicle dynamics - Results from a motorcycle field test

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ABSTRACT

Powered two-wheelers are a common means of transport all over the world. In several countries, primary motorcycles with high displacement involve another purpose, namely motorcycling is a leisure activity. Motorcycles are used as tools of transport pleasure as opposed to being purely used for individual commuting purposes. The aim of the current study involves investigating the relation between experienced riding pleasure and riding behavior in a field test. Specifically, $N = 12$ motorcyclists between 21 and 66 years of age were observed while riding for approximately 8 h on public roads. The measurement setup included a logger for vehicle dynamics and vehicle handling data, GNSS data, video data, and subjective measures recorded as audio comments at predefined points of interest along the round course. A comprehensive dataset with more than 6000 km of motorcycling was gathered. The results indicate that parameters of lateral vehicle behavior, such as the maximum lean angle, reflected riding pleasure. Interestingly, this is applicable for curvy sections as well as straight roads. High ratings of riding pleasure correlated with riding in snaky lines as a type of self-stimulation on straight sections. Longitudinal vehicle dynamics, such as the range of accelerations, tend to increase with the riding pleasure in curves. Hence, the effects are smaller than those for lateral vehicle behavior and not visible on straight sections. Generally, curvy sections on rural roads produce higher pleasure than straight roads. On a global level, riding pleasure increases during the first few hours of riding and subsequently decreases with respect to the time on task. The results are discussed in the context of studies on driving pleasure from the automotive sector and more fundamental psychological theories that explain pleasure as a physiological stimulation or flow. Several individuals ride motorcycles to experience pleasure. A better understanding of rider behavior in these situations can aid in deriving proper assistance and to provide individual support to a rider, thereby increasing riding pleasure as well as safety.

1. Introduction

The pattern of use for motorcycles shifted towards leisure riding since the mid-1990s (Jamson and Chorlton, 2009). This is at least applicable for central European countries, such as Germany or Austria, where riding pleasure plays an important role when compared to the use of powered two-wheelers (PTW) for commuting.

For example, Jordan (2000) defines pleasure and differentiates four types of pleasure (i.e., physio-pleasure, socio-pleasure, ideo-pleasure, and psycho-pleasure). Physio-pleasure is a result of positive sensory stimulation. Psycho-pleasure is defined as a result of joyful interaction with a product characterized through high usability. These two sources of pleasure appear to be relevant to motorcycling, while pleasure arising from social interaction and special aesthetics of a product are less linked to motorcycling. For example, Tischler and Renner (2007) define driving pleasure. They consider driving pleasure as an emotional state of a person that is determined by the current sensual experience of the interaction between driver, vehicle, and environment. They postulate a closed loop model to describe the emergence of driving pleasure. The studies indicate that drivers exhibit an intended level of activity and

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select driving behavior to reach the level by considering available driver skills (see also Fuller, 2000). Resources and restrictions in terms of vehicle characteristics and environmental influences moderate the action's success. Furthermore, the authors assumed that driving pleasure is a result of active and dynamic driving in contrast to feeling under-stimulated or bored (see also, Engelbrecht et al., 2009; Knobel et al., 2013; Roßner et al., 2015). However, at least for the passenger-car sector, this definition does not sufficiently describe the construct of driving pleasure. Additionally, factors including comfort play an important role (Engelbrecht et al., 2009; Hartwich et al., 2018). While considering motorcycles as opposed to passenger cars, the role of active and dynamic driving is seemingly more important and especially while focusing on leisure usage.

From a psychological point of view, the origin of fun or pleasure is significantly linked to the motivation of conducting a certain task (Blythe and Hassenzahl, 2003; Deci and Ryan, 1985). A differentiation between actions that are conducted due to an intrinsic or extrinsic motivation appears to be necessary. Rheinberg (1989) defines actions as intrinsically motivated when conducted for self-purpose and not for its outcome. Actions that are motivated intrinsically do not need any further reward. It is assumed that motorcycling corresponds to the aforementioned type of activity for most riders. Another helpful concept to understand the origin of riding pleasure is flow, and this was introduced by Csikszentmihalyi (2000). Flow is described as a state of being neither unchallenged nor over-challenged while conducting a certain task. It is described as full focus on the task itself (absorption) that matches an individual's skills. The rider's behavior in maneuvering and stabilizing the motorcycle is a possibility whereby task demands are regulated, and the flow balance is maintained (Donges, 1978). The interpretation is supported by Pöschel et al. (2011) who obtained a positive effect of free riding on experienced riding pleasure. The riders' possibility for self-regulation is minimized by following other vehicles in traffic. This makes it harder to maintain a balance between task demands and rider skills. With respect to motorcycle riding, a relation between being in a flow-state while riding a motorcycle and experiencing riding pleasure is assumed (Rheinberg, 2000). In addition to the interaction between rider and vehicle, the environment influences the riding pleasure experienced. Road characteristics, such as curvature or road surface conditions, impact the perceived level of riding pleasure (Engelbrecht, 2013). Typically, high friction and curvy sections are related to high riding pleasure. This is especially true while focusing on dynamic driving as opposed to comfortable cruising. One of the major differences between single-track vehicles, such as motorcycles, and cars pertains to how they handle a curve. The PTW is stabilized by producing adequate lean angles in curves. Given this particular characteristic, the hypothesis involves determining increased riding pleasure especially on curvy sections when compared to straight roads.

The investigation of riding pleasure and its relation to vehicle dynamics requires objective riding data and an external criterion indicating perceived pleasure. The latter is commonly performed with subjective ratings (Amado et al., 2014; Toda and Kageyama, 2007). In a study on driving pleasure, $N = 51$ drivers drove four different cars on a closed test track and in public traffic (Tischler and Renner, 2007). Comfort and sportiness appeared as the optimal predictors in a regression model for driving pleasure. Vehicle data analysis on sporty test track laps from $N = 14$ professional drivers revealed that higher mean acceleration, higher maximum lateral acceleration, and low steering wheel angles were related to driving pleasure. Hence, the effect was not obtained for nonprofessional drivers.

Given the cited results from fundamental and automotive studies, the following hypotheses are obtained:

- Motorcycle riding is a task with high control involving sensory stimulation, task demands, and joyful interaction with a product. Therefore, it is hypothesized that higher levels of experienced pleasure are reflected in vehicle dynamics data.
- Based on previous studies in the automotive sector, high pleasure should be reflected in measures of longitudinal as well as lateral vehicle dynamics.
- Given the specific characteristics of a single-track vehicle (i.e., necessary lean angle while taking a curve), it is assumed that major effects should be visible on curvy roads as opposed to straight roads.

To the best of the authors' knowledge, this is the first study in which a significant amount of vehicle dynamics data is set in relation to ratings of subjectively experienced pleasure in the motorcycle sector. Therefore, explorative analyses are included next to hypotheses driven investigations.

2. Methods

2.1. Basic experimental setup

A test course in public traffic was defined, which contained sections with varying road characteristics with a focus on curvy rural sections. Nonprofessional riders were invited to participate in the experiment. They were asked to ride up to eight laps on the test course during a single day. At predefined positions along the track, riders were asked to rate their current state to obtain information on subjectively experienced riding pleasure. The aim involved investigating the relationship between riding pleasure and vehicle dynamics that were constantly logged.

2.2. Test course

Data collection occurred in Spain on a pre-defined round course on public roads. The round course with a length of approximately 78 km was completed eight times during one day (8 laps). It consisted of different types of roads, namely a section on the highway, longer parts on rural roads with varying curvature, and urban sections. It commenced on rural roads with significantly curvy characteristics interrupted by a few urban areas. After approximately two thirds of the course, it was necessary to pass a bigger city before entering a highway leading back to the starting point. The aim involved achieving a representative nature of the road characteristics selected for leisure riding. On average, it took approximately 1 h to complete one round of the course.

2.3. Test motorcycles

For the study, four motorbikes of the type KTM 1290 Super Duke R were used (see Fig. 1). Three of the four motorcycles were constantly in use while the fourth motorcycle was a backup in the event of technical issues. All vehicles were equipped with a data recording system that logged controller area network (CAN)-signals and global navigation satellite system (GNSS)-data. The collected data contains information on vehicle dynamics (e.g., velocity, acceleration, and lean angle) as well as vehicle handling (e.g., clutch lever position and usage of indicator). Furthermore, cameras were fitted to the helmets and logged videos of the rides in conjunction with audio comments.

Each motorbike was fitted with a navigation system containing the pre-programmed round course. The measurement setup was designed to not influence riding dynamics and to be discreet such that other traffic participants do not react unnaturally (see Fig. 1).

2.4. Measures

Data on vehicle dynamics and vehicle handling were logged at a frequency of 100 Hz. Additionally, video data from a camera mounted on top of the helmet (rider view) combined with auditory comments of the riders while riding were recorded. The latter were used to gather subjective ratings. Along the test track, eight points of interest were defined and programmed into the navigation system. While passing these points of interest, the riders were asked to rate their current state

Fig. 1. Motorbike and rider fully equipped for the test and motorbike fitted with data logger and GNSS-antenna.

by providing an audio comment. The riders rated their current mental and bodily exhaustion in conjunction with their current perceived riding pleasure. The ratings were given on a 15-point-categorical classification scale with verbal anchors (see Fig. 2).

How do you rate your riding pleasure at the moment?

2.5. Procedure

The experiment was conducted on four consecutive days. Each day, three riders were tested simultaneously. The eight laps were split into four double-laps with breaks in between. In every break, the riders rated the weather respectively road surface conditions. If the majority of a lap was ridden in dry conditions, the lap was labeled ‘dry’. If the majority was ridden in rain, the lap was labeled ‘wet’. Daytime temperatures varied between 10 °C and 22 °C. The morning session and the afternoon session consisted of two double-laps each and were separated by a lunch break. Prior to starting the first double-lap, the riders answered a short questionnaire on their current state. The same was conducted during each break and in the evening. The riders started individually with a time-lag of 20 min to ensure that they were not riding in a group. Additionally, experimenters were not present while riding. This procedure provided all riders with the freedom to select their own riding style (e.g., more sporty, or relaxed). Furthermore, instructions on how to ride the bike were absent. However, the riders were instructed to end the test in case they felt unable to continue riding safely. Two riders selected the aforementioned option (after lap six and after lap seven).

2.6. Panel description

A total of $N = 12$ riders participated in the study, and one of the riders was female. Two of the participants rode their bike throughout all seasons while the remaining participants only rode their bikes seasonally. The participants received their driving licenses for motorbikes between 1968 and 2015. Therefore, the driving experience between the participants varied significantly (see Table 1). All riders were commonly recruited by the three project partners and came specifically to Spain to participate in the study. There were no professional riders in the sample.

3. Data analysis

Based on GNSS-position, riding data was segmented into sections with different road characteristics as follows (values in parenthesis represent percentage of length of total course):

Table 1
Panel description (N = 12).

	Mean	Standard deviation	Minimum	Maximum
Age in *years*	39	14	21	66
Motorcycle license since *XX years*	19	15	1	48
Motorcycle mileage covered during the last 12 months in *km*	4900	3147	700	10,000

- straight rural sections (20.6%)
- moderate curvy rural sections (16.4%)
- curvy rural sections (24.4%)
- highway sections (23.0%)
- urban sections (10.7%)
- intersections (0.6%)
- roundabouts (1.8%)
- exits/entries to highway (1.8%)
- unclassified (0.7%)

The classification was performed via an expert rating by two experienced motorcycle researchers. Based on the video coding of road characteristics, curvy rural sections and straight sections on rural roads were used to analyze the relation between riding dynamics and riding pleasure. In order to replicate the findings on curvy sections with an approach that was independent of detailed knowledge related to the selected route, an algorithm that detected curves based on riding behavior was implemented. The rider is assumed to take a curve if the absolute lean angle exceeds 10° for more than 50 m. The validity of this definition of curves was verified with a random selection of detected curves and corresponding video data. Table 2 shows the number and average length and duration of the analyzed situational instances.

For straight and curvy sections as well as for individual curves the following parameters of longitudinal and lateral riding dynamics were calculated:

- Minimum longitudinal acceleration (equals deceleration): min(ax) in m/s2;

not at all	very little			little			medium			much			very much		
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**

Fig. 2. Scale used for online rating of riding pleasure (Heller, 1985).

Table 2
Description of the analyzed database: average number per lap, average length and duration as well as total number of instances for straight and curvy sections and curves identified based on riding behavior.

	m(N/lap)	m(length)[m]	m(duration)[s]	N Total
Straight sections	43	375	15.5	3655
Curvy sections	37	510	27.2	3219
Curves	157	84	4.2	13643

- Maximum longitudinal acceleration: max(ax) in m/s2;
- Range between min(ax) and max(ax): range(ax) in m/s2;
- Maximum absolute lean angle: max(|LeanAngle|) in degrees.

Additionally, the curvature $\kappa(t)$ was estimated by firstly transforming the measured GNSS data into UTM coordinates. Then, the first and second time-derivatives of the lateral and longitudinal coordinates were calculated using a fast Fourier transform (FFT)-based approach with low pass characteristics, utilizing a border frequency of 2 Hz (see equation (1)).

$$\kappa(t) = \frac{\dot{x}(t)\ddot{y}(t) - \ddot{x}(t)\dot{y}(t)}{\left(\dot{x}(t)^2 + \dot{y}(t)^2\right)^{3/2}} \quad \text{with } \dot{x}(t) = \frac{\partial x}{\partial t} \tag{1}$$

Each sign change of the curvature describes the beginning of a new corner segment. As mentioned above, only such segments with a course angle change greater than 10° were further investigated. This process generated approx. 15,000 single segments, cumulated from all riders. For every segment, a list of characteristic values was calculated, e.g., containing the maximum roll angle $\widehat{\phi}$, the maximum curvature $\widehat{\kappa}$ and the time duration T_{segment} for the pass through a curve.

For the statistical analysis, parameters are first calculated per identified situational instance (e.g., straight section or curve) and then averaged per rider. The averaged values are used for graphs and statistics. These graphs show the arithmetic mean and 95% confidence interval unless otherwise stated.

4. Results

The test course was deliberately chosen to enable free riding without surrounding traffic that might influence rider behavior. Based on video analyses, this worked well for rural sections and highways so that only rare events with other traffic participants occurred which can be neglected. Consequently, the analyzed data is interpreted as containing freely chosen rider behavior. An exception to that were transits through urban areas.

Fig. 3 shows the development of subjective riding pleasure as a function of time on task. There are eight laps with eight ratings each (see Fig. 3 left). The ratings for the first half of each lap exhibit higher values for riding pleasure when compared with that in the second half. Generally, the subjective ratings at the start indicate high riding pleasure. There is an increase towards extremely high levels of riding pleasure within the morning session and a decrease towards medium to low levels of riding pleasure ratings at the end of the experiment. Prior to the lunch break (between lap 4 and 5), there is a slight dip in the ratings. During the afternoon session, there is a global continuous decrease in experienced riding pleasure. It should be noted that the rated riding pleasure in the very last rating given on a test day increases. This is also shown in Fig. 3 (right) that compares ratings on straight sections and in curves. It should also be noted that a pattern exists within each lap. Specifically, riding pleasure decreases at the end of each lap for laps 2–5. The focus of the analyses is on rural sections (and especially on curves), and thus the experienced riding pleasure is separately shown for curvy and straight sections. The ratings on curvy sections on average exceed those on straight sections. Nevertheless, the overall pattern appears to be identical (see Fig. 3 right).

The following analyses relate subjective ratings of riding pleasure to vehicle dynamics parameters on specific road categories. For further analysis, a 15-point categorical classification scale (Heller, 1985) for riding pleasure is condensed into a five-point scale. Three neighboring ratings are merged into one data point where 1 indicates least pleasure and 5 indicates highest pleasure. Additionally, 0 ratings were never assigned and are therefore not shown. Fig. 4 shows different parameters of riding dynamics for straight rural sections as a function of the rated riding pleasure.

For straight sections of the roads, there is no statistically significant systematic change in the longitudinal dynamics with variations in the subjective riding pleasure (min(ax): $F(4,35) < 1$ Fig. 4 upper left, max (ax): $F(4,35) < 1$ Fig. 4 upper right, m(range(ax)): $F(4,35) < 1$ Fig. 4 lower left, max(v): $F(4,35) < 1$ not depicted). However, maximum absolute lean angle significantly increases with increases in the riding pleasure ($F(4,35) = 6.07$, $p < .001$, $\eta^2_p = 0.410$ Fig. 4 lower right). Increases in riding pleasure are related to riding in a snaky line on geographically straight roads.

This effect seen for the lateral dynamics is also applicable for curvy sections (see Fig. 5). Increases in rated riding pleasure are related to an increase in the maximum lean angle ($F(4,35) = 10.66$, $p < .001$, $\eta^2_p = 0.550$ Fig. 5 lower right). Furthermore, there is a marginally significant effect for more dynamic longitudinal riding behavior with increases in riding pleasure as indicated by a higher range of accelerations ($F(4,35) = 2.38$, $p = .070$, $\eta^2_p = 0.210$ Fig. 5 lower left), and this is mainly due to stronger braking in curves ($F(4,35) = 2.12$, $p = .099$, $\eta^2_p = 0.190$ Fig. 5 upper left). There is no statistically significant effect of riding pleasure on maximum acceleration ($F(4,35) = 1.20$, $p = .327$ Fig. 5 upper right).

A comparable analysis of vehicle dynamics data in relation to subjective ratings is performed based on curves that are identified by riding behavior as opposed to the GNSS classification (see Fig. 6). The results

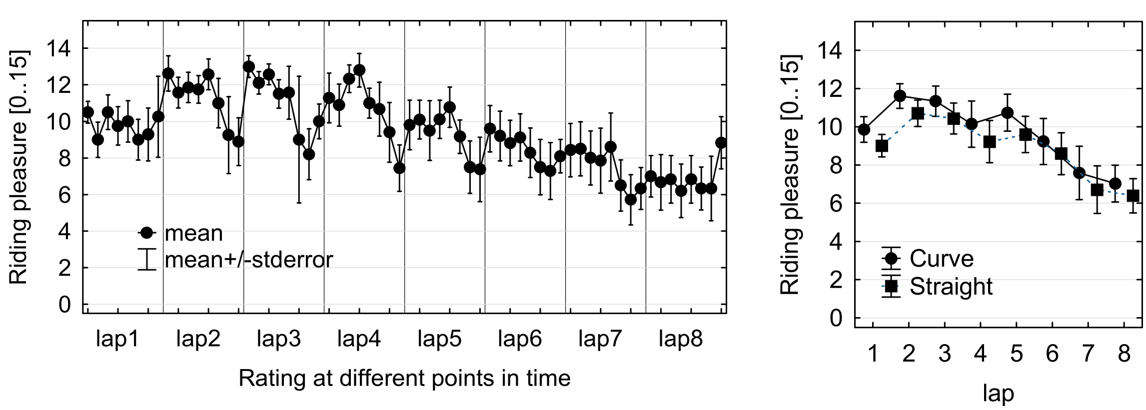

Fig. 3. Riding pleasure as a function of time on task with 8 ratings per lap (left)) and riding pleasure separated for straight roads and curvy sections as a function of time on task (right).

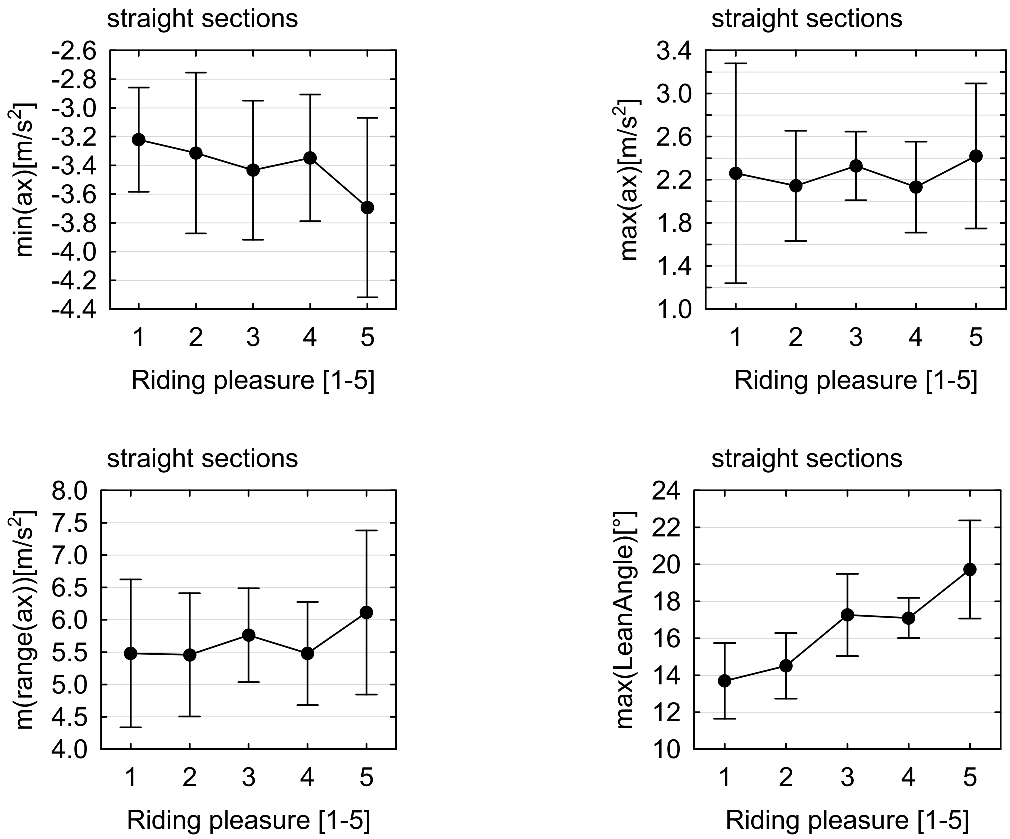

Fig. 4. Parameters of longitudinal and lateral riding dynamics as a function of subjective riding pleasure on straight rural sections.

replicate the results for the aforementioned curvy sections. There is a significant increase in maximum absolute lean angle with increases in riding pleasure ($F(4,35) = 9.83, p < .001, \eta^2_p = 0.520$ Fig. 6 lower right). The tendency for increases in longitudinal dynamics with increases in riding pleasure is only visually seen in maximum negative ($F(4,35) = 1.88, p = .135$ Fig. 6 upper left) and positive ($F(4, 35) = 1.20, p = .327$ Fig. 6 upper right) accelerations, and thereby the range of accelerations ($F(4,35) = 1.92, p = .130$ Fig. 6 lower left) for single curves. However, the effects are not statistically significant.

On a more detailed level, it can still be seen from Fig. 7 that higher roll angles correlate with higher ratings of riding pleasure. Hence, there is a significant spread. Sections with high pleasure ratings include low roll angles as well. Same holds true the other way round. Sections with low pleasure ratings include high roll angles, too. Generally, wet road surface conditions decrease pleasure ratings compared to dry conditions. The above mentioned results seem to hold true across road segments with different curvature and speed. Yet, it can obviously be seen that higher speed is measured in segments with lower curvature and consequently a lower roll angle. The highest variety in chosen roll angles appears on road segments with a minimum radius below 200 m and a moderate speed range between 50 km/h and 80 km/h in dry conditions (second column, first row in Fig. 7).

Fig. 8 shows the relation between longitudinal and lateral vehicle dynamics related to different levels of subjectively rated riding pleasure. The y-axis of each plot shows the maximum absolute lean angle for a curve. Correspondingly, on the x-axis, the used range of longitudinal accelerations for a curve is shown. Thus, each curve is depicted as a datapoint defined by these two parameters. A data point in the plot equals a curve identified based on riding behavior. As shown in the figure, there is always a proportion of curves with low lateral and longitudinal dynamics as depicted in the lower left corner of the graphs. The number of curves with higher dynamics increases with increases in the rated riding pleasure. A higher maximum lean angle is accompanied by stronger deceleration at the beginning of the curve and acceleration while leaving the curve.

Based on Fig. 8, curves with a range of accelerations less than 6 m/s^2 and a maximum absolute lean angle less than 30° are defined as "not dynamically ridden", and all other curves are defined as "dynamically ridden". The same thresholds are used for all participants, and they are defined based on the values for the lowest category of subjective riding pleasure. For each rider and each level of riding pleasure, the proportion of dynamically ridden curves is calculated. There is a significant increase in the proportion with increases in the riding pleasure ($F(4,35) = 18.90$, $p < .001$, see Fig. 9 left). As shown in Fig. 9 (right), for ten out of twelve riders, the proportion of dynamically ridden curves increases with higher levels of riding pleasure. The evaluation per rider is only based on a visual impression. Given the limited number of curves per rider and that riders mostly experience only a subset of subjective categories of riding pleasure, the relation between riding dynamics and subjective pleasure is not statistically verified on a rider level.

5. Discussion

The main aim of the study involves investigating the relation between subjectively experienced riding pleasure and objectively measurable vehicle dynamics data. The results indicate that parameters of lateral vehicle behavior especially indicated riding pleasure independent of road characteristics.

Specifically, in the morning session, the ratings assigned during the first half of the round course are higher and increase until noon. At the end of every lap, values for riding pleasure decrease. This is possibly explained by the road category. Each lap begins with longer, more or less curvy sections on rural roads. This is followed by urban areas and ends with a highway section. Riders seemingly experience rural roads as more

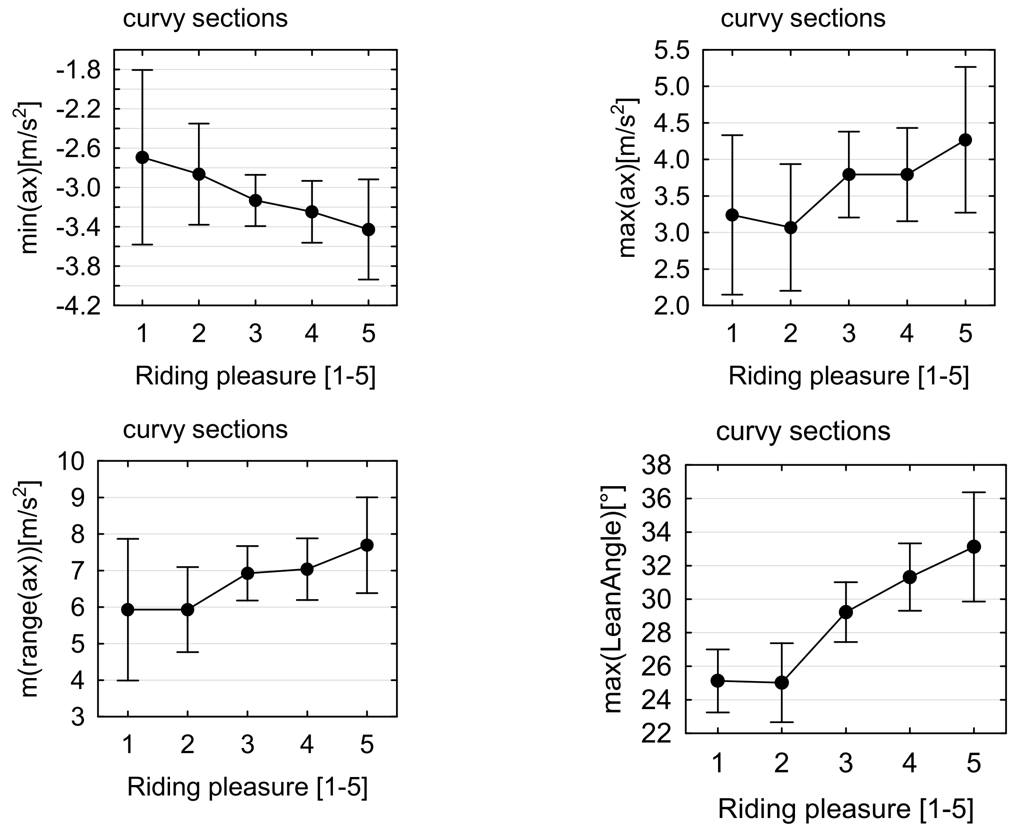

Fig. 5. Parameters of longitudinal and lateral riding dynamics as a function of subjective riding pleasure on curvy rural sections.

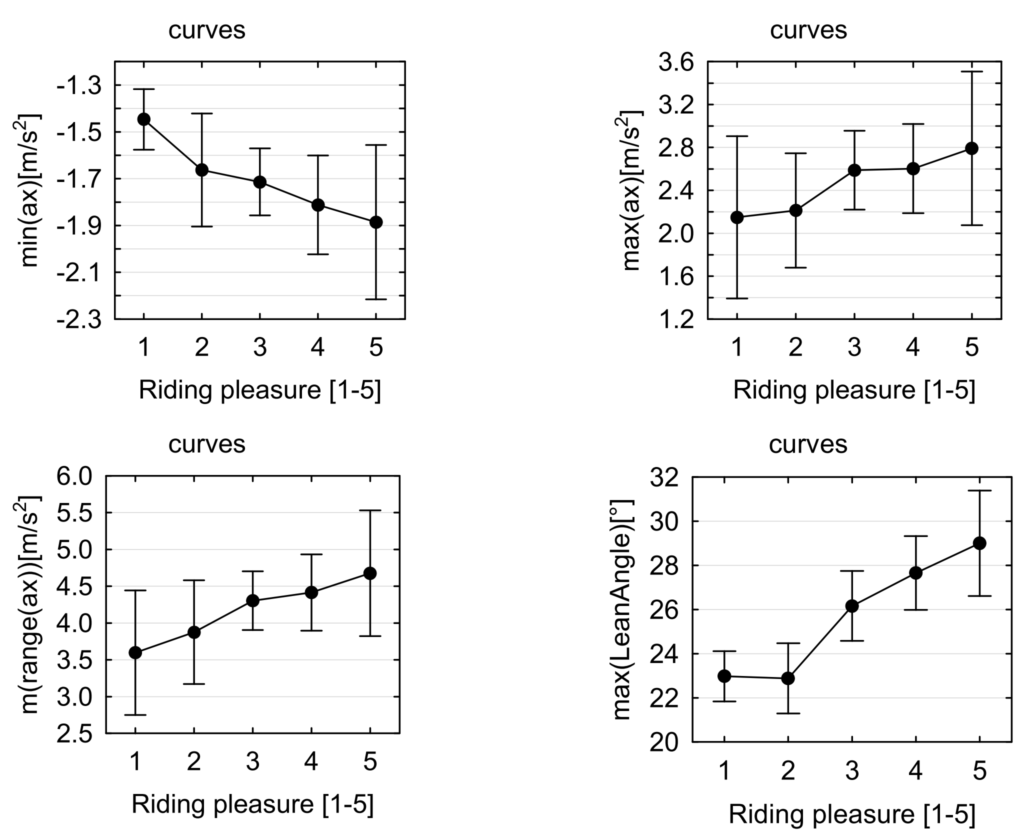

Fig. 6. Parameters of longitudinal and lateral riding dynamics as a function of subjective riding pleasure on curves identified based on riding behavior.

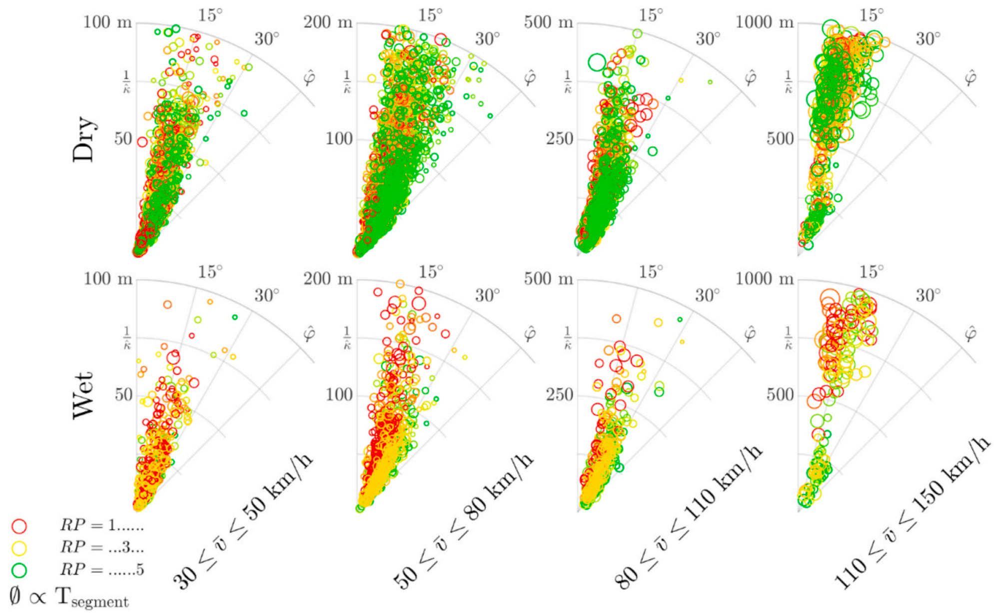

Fig. 7. Distribution of maximum roll angles and trajectory curvature of single corner segments in relation to subjectively evaluated riding pleasure (color coded). The subplots discriminate between dry and wet conditions (per row) and the range of the segment's mean velocity $\bar{v}$ (per column). The diameter of each circle indicates the duration of the segment. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

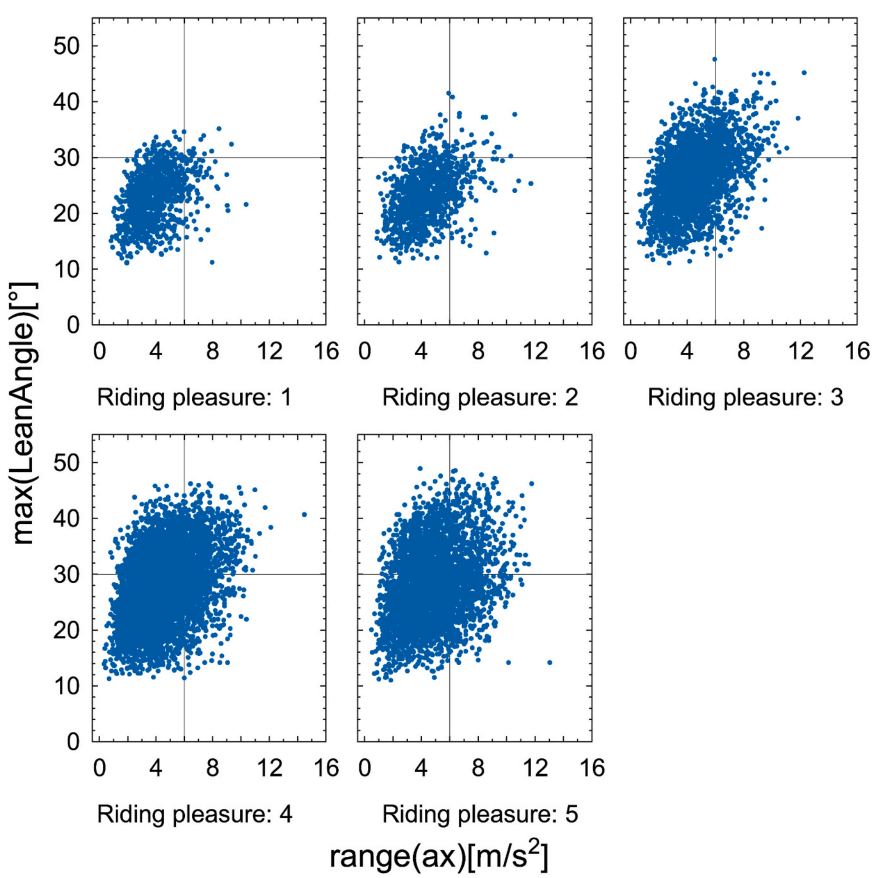

Fig. 8. Relation between the utilized range of longitudinal acceleration and maximum absolute lean angle for different levels of subjectively rated riding pleasure. The lower left rectangular sector denotes curves as "not dynamically ridden". The three other sectors are denoted as "dynamically ridden".

joyful than urban areas and highways. This explanation seems likely as the increase in reported pleasure can also be observed at the beginning of lap two, four and six. As the riders always completed double-laps, there was no rest prior to these laps to recover, which could otherwise explain the increase in riding pleasure at the beginning of each lap. The increase in each very last rating is interpreted as a positive feeling that is potentially because the target riding distance for eight laps is reached. The effect is a well-known phenomenon in sports (Triplett, 1898). This

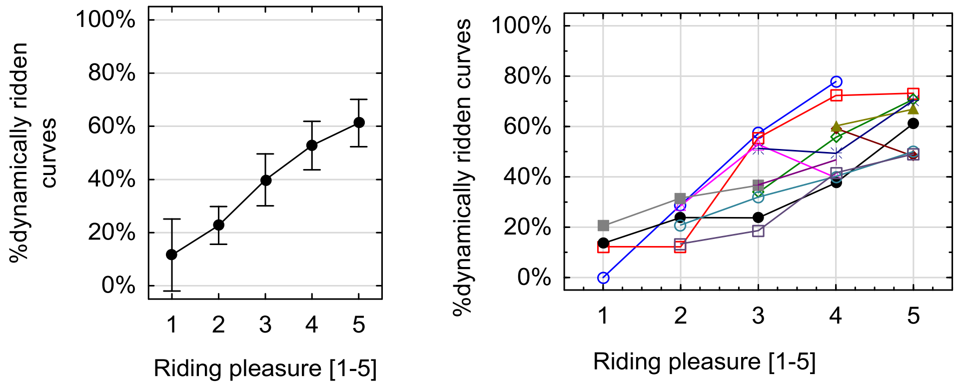

Fig. 9. Proportion of dynamically ridden curves for different levels of riding pleasure. The left graph shows average values for the panel, while the right graph displays the same effect on an individual level (every line represents one of the twelve riders).

also holds true for the lunch-time dip in connection with a recovery-phase after the break period.

The global increase in the level of pleasure until noon might be attributed to growing confidence and excitement as riders get to know the motorcycle as well as the road better. According to Jordan (1998) these feelings are associated with increasing pleasure. The global decrease in the level of rated pleasure towards the end can be an effect of fatigue or strain. Another possible explanation is based on motivational theories (Rheinberg, 1989). The intrinsic motivation for riding might decrease throughout the day and the extrinsic motivation (i.e., "The experimenter wants me to complete the tour.") may prevail. Amrutkar et al. (2011) investigated the ergonomic posture for motorcycle riding. According to their questionnaire study, riders experience discomfort in their upper body parts (e.g., neck, upper back). This might at least partly be due to constant aerodynamic drag and whole-body vibration exposure (Chen et al., 2009). This discomfort increases with longer periods of riding and may also contribute to lower pleasure ratings over the course of time. The effect of time on task was already obtained for driving respectively riding (e.g., Travers and Jennings, 1980; van der Hulst et al., 2001). A limitation of the study design was that only one rather sporty motorcycle model was tested. It is likely that different motorcycle types and consequently comfort, engine characteristics etc. might influence experienced riding pleasure over time. Further research would be necessary to assess the impact of these factors.

Based on data logged during unsupervised riding, a connection between lateral riding dynamics and riding pleasure is obtained. Specifically, on curvy sections, a strong relation exists between riding dynamics and experienced riding pleasure. Larger lean angles in curves as well as stronger acceleration and braking maneuvers are related to riding pleasure. This replicates the findings given by Tischler and Renner (2007) who obtained higher mean acceleration and higher maximum lateral acceleration as related to driving pleasure. A comparison between the steering wheel and handlebar angle is not performed given the physical differences in steering a motorcycle relative to steering a car. Generally, the expected relation between road characteristics and riding pleasure is obtained. The perceived riding pleasure is on an absolute higher level on curvy sections. It should be noted that, even on straight sections, the correlation between riding pleasure and lateral dynamics exceeds the correlation to longitudinal dynamics. Initially, this appears to contradict Engelbrecht (2013) findings. Hence, there are several possible explanations for that result. An explanation is that riders can overtake more dynamically with increases in the riding pleasure, thereby leading to higher lean angles through more dynamic lane changes. Another reason emphasized by video data is that riders choose to ride in snaky lines on straight sections more frequently with increases in riding pleasure. Thereby, motorcyclists artificially increase the demanding characteristics of the road section. This in turn appears to shift the perceived situational workload towards a level that matches an individual's own skills better and avoids the problem of underload (Csikszentmihalyi, 1999; Fuller, 2000). This behavior was observed regularly in significantly monotonous situations. Furthermore, the proportion of high maximum lean angles with stronger braking or accelerating increases with increases in the experienced riding pleasure.

Even if riding pleasure and chosen lean angle respectively curvature relate to each other, it seems as if riding pleasure cannot be purely determined by the characteristics of curves. Neither a specific curvature nor a velocity (which are interdependent, of course) determine high pleasure ratings. A clear limitation for interpreting the data is that pleasure ratings were given for homogeneous sections instead of single curves. Furthermore, one important aspect that has not been investigated in this study is the three-dimensionality of curves. Apart from curvature, the topography of a specific curve might play an important role. Compared to artificially created curves on a closed test-track, a limitation of the present study is that the round course on public roads determined the curvatures and topography to be investigated. It is uncontested that experienced riding pleasure seems to be of a multicausal nature. One could imagine a variety of reasons going beyond the named characteristics of curves, motorcycle type or time on task (e.g., motivational factors for riding, road surface conditions such as dirt or potholes). In line with Tischler and Renner (2007) expectations, riders experienced more pleasure while riding in dry conditions compared to riding in wet conditions. PTW typical low protection against environmental influences, lower friction or at least decreasing confidence in friction might explain increased discomfort which relates negatively to pleasure (Engelbrecht, 2013). More research is necessary to reveal causal relations between specific factors and experienced pleasure.

In summary, a relation exists between vehicle dynamics and experienced riding pleasure. This agrees with the results obtained in extant studies and fosters the assumption that driving (or in this case riding) pleasure is a result of active and dynamic driving (Engelbrecht et al., 2009; Knobel et al., 2013; Roßner et al., 2015; Tischler and Renner, 2007). Specifically, the parameters of lateral vehicle dynamics, such as a higher maximum lean angle, subjectively reflect perceived riding pleasure. The effect is more prominent on curvy sections. As previously stated, the experimental setup did not focus on rider comfort that can also play a role in riding pleasure (Tischler and Renner, 2007). Nevertheless, the fact that riding pleasure decreased over the day can be interpreted as reduced comfort or fatigue that results from the long riding distance. An alternative explanation is that the course loses its novelty and thereby loses attraction after each lap. An argument contradicting this interpretation is that familiarity with the road sections facilitates smooth riding. Riding pleasure is still a niche area and many other potentially contributing factors in terms of ergonomics, such as protective clothing or body posture, remain subject to future investigations (Robertson et al., 2009).

6. Conclusion

Generally, vehicle dynamics patterns are correlated with rated riding pleasure. The relation between subjectively experienced riding pleasure and lateral vehicle dynamics is more stable than the relation with longitudinal vehicle dynamics. The maximum lean angle increases constantly with increases in the riding pleasure. This also applies to different road types (e.g., straight vs. curvy roads). Generally, the results indicated that a significant relation exists between the objective behavior of riders and their subjectively experienced pleasure.

It is more likely that analyses of riding behavior based on maneuvers that are purely identified by vehicle dynamics data will be implemented in possible future assistance systems since valid external data, such as GNSS or map matching, is not necessary. The discussed results demonstrated the general feasibility to develop algorithms that work based on already available vehicle dynamics data. A potential implication of these results is the application of individual rider behavior to rider assistance system design and automatic adaptation of a motorcycle to the current and individual needs of the rider. The individual tuning is expected to increase the acceptance of such assistance systems and consequently pleasure and safety. Further research is needed to better understand the important link from experienced riding pleasure to safety.

The analyzed dataset contained more than 6000 km of naturalistic riding including video- and audio-streams, GNSS data, vehicle dynamics data, and psychological evaluations of the riders resulting from an interdisciplinary research cooperation. The analysis of riding pleasure in conjunction with vehicle dynamics data is only one possibility wherein the highly comprehensive dataset is used. It is conceivable that more sophisticated analyses to provide a better understanding of rider behavior, derive possible assistance, and finally increase rider safety, can be performed with the data available and in future studies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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