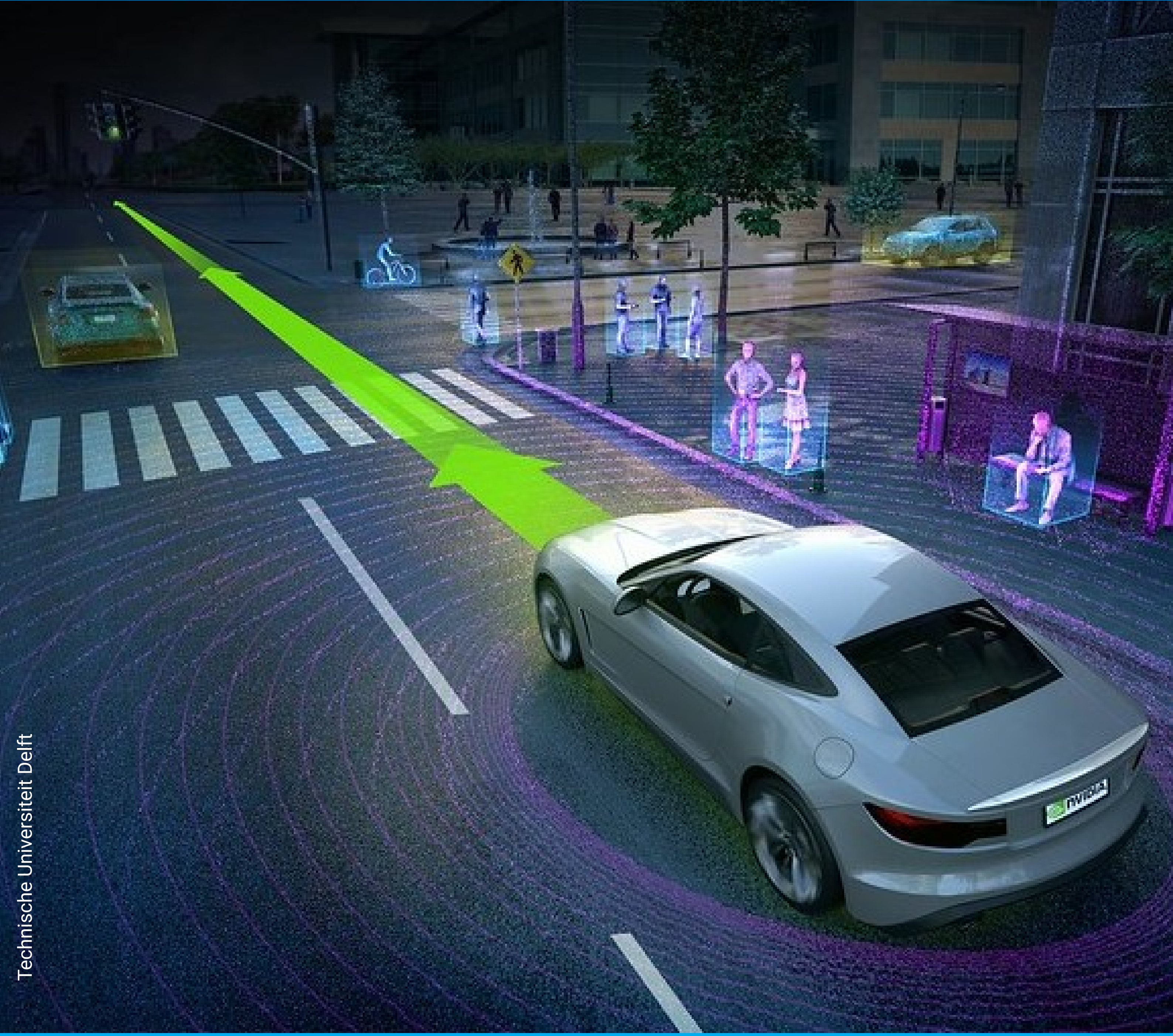

Technische Universiteit Delft

The Effect of Complementing Haptic Shared Control with Visual Feedback on Driving Behaviour during Overtake Manoeuvres

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by

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K.M. Labrujere
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Paper

The Effect of Complementing Haptic Shared Control with Visual Feedback on Driving Behaviour during Overtake Manoeuvres

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Abstract—**Driving with driver assistance systems utilising haptic shared control (HSC) can lead to annoyance, or even disuse, when the intent of both entities differs. In order to increase compliance and acceptance of these systems, this study explores two types of visual information projected onto the outside scenery. One visualisation portrays only the intended trajectory of the HSC system, whereas the other visualisation complements this by showing the manoeuvring boundaries of the car. These visualisations were evaluated in a human-in-the-loop simulator study focused on supporting an early and late car overtake manoeuvre, initiated by HSC. Although most participants reported a preference for visualisation of both the intended trajectory as manoeuvring boundaries, results in terms of torque conflicts and position conflicts indicated no significant differences between the visualisations. Subsequent analysis, however, indicated that this was probably caused by the variability in how participants used the visualisations in combination with their apparent preferences in performing the overtake manoeuvre. In conclusion, supporting HSC with visual information does not improve compliance, but shows an improvement in acceptance. For future work it is recommended to further investigate the impact of visualisations on intra-driver variability.**

Keywords*—*Single Trajectory Haptic Shared Control, Ecological Interface Design, Visual Feedback, Conflicts, Compliance, Driving Behavior, Overtake Manoeuvre

I. INTRODUCTION

Advanced Driver Assistance Systems (ADAS) are fast-growing applications in present-day vehicles, as it shows benefits in safety, comfort and control effort compared to manual driving [1] [2]. Driving with these systems shifts the role of the driver from manual to assisted or even supervisory control, bringing the challenge to let the driver use ADAS accordingly, and prevent disuse. Disuse of the automation refers to turning off the automation, where it could be helpful [3]. The distinction between use and disuse can mainly be found in the experienced reliability and trust, which at the same time depends on the functioning of the automation [4] and the understanding of the system [5]. Design guidelines for improving understanding towards automation, and vice versa, suggest that Haptic Shared Control (HSC) is a promising solution [6]. This cooperative form of automation, enables communication between both entities and, at the same time, keeps the automation benefits (e.g. fast response and accurate control) [7].

During driving with HSC both the automation and the driver simultaneously provide input torques on the steering wheel, allowing for a continuous interaction between both entities. This way of communicating, leads to an improved understanding towards the intent of the other [6], which at the same time could be beneficial for the experienced trust and reliability. However, conflicts between HSC and driver [8] [9] indicate a mismatch in intent between both entities, which again can lead to annoyance, and thereby disuse of HSC. It is suggested that these mismatches can be caused by either a poor design of HSC, where the effect on the human operator is not sufficiently considered (i.e. automation abuse) [6] [10] [3], or by the limited information HSC is providing.

By means of haptic forces only limited, on short notice, information can be provided [11] [12], meaning that HSC is lacking information about the intent of the system in the future. This should not lead to problems, when the intent of HSC and driver is exactly the same. The degree of match between intent of HSC and driver can be described by the term inner human-machine compatibility [13], where machine can be adjusted to human preferences and vice versa. An example of a poor match is driving with an one-size-fits-all controller, as the intent of HSC and driver do not coincide shown by conflicts [8]. An improved compatibility can be found when HSC has been individualized to a driver's behaviour, shown by a decrease in conflicts when driving in curves [14]. This is a method to improve inner human-machine compatibility, by adjusting the machine towards the human preferences.

Promising results have been found for individualising a controller for entering a curve, however, individualising more complex driving situations is more challenging. Driving is defined in three levels of planning, respectively strategical, tactical, and operational [15]. Where entering a curve only consists of planning on operational level, an overtake manoeuvre both contains tactical and operational level. Therefore, an overtake manoeuvre can be planned on multiple time moments, and executed in multiple ways.

In order to deal with both tactical and operational level during an overtake, a method should be found to improve inner human-machine compatibility. This can either be done by designing a HSC which fits to driver's preference, other than individualising, or by trying to let drivers adjust their behaviour towards HSC's desired input. Benloucif et al. [16] designed a cooperative trajectory planner, which allows the driver to perform his/her desired trajectory more easily. However, this comes at the expense of the optimising strategy of the machine, as a driver can easily overrule the system. Moreover, conflicts between cooperative trajectory planner and driver are still existing, where it was recommended to provide visual feedback in order to improve understanding towards automation's future actions and therefore possibly reduce conflicts. The second possible solution was to try to adjust a participant's driving style towards that of the machine, whereby a driver should be aware of the intent of the controller. As increasing the strength of haptic cues make communications less clear [17], the goal is to make the intent of HSC transparent.

To make the intent of HSC transparent, visual feedback should be added, as this is the most prevalent solution [18]. This feedback modality provides information on longer time scales, what HSC is lacking, and thereby, making interpretation possible [19] [20]. Multiple visualisation methods are existing, where it is suggested that some of them have an optimising strategy, where others have a satisficing strategy. An optimising based visualisation method, is visualising HSC intended trajectory. Here it is shown that an improved understanding and faster responses to automation failures are reached [21]. However, it is not clear what the impact is on driving behaviour in terms of adjustments in driving behaviour towards HSC intended trajectory.

Another approach, as well used for visualisation, is Ecological Interface Design (EID). This design approach focuses on visualizing the available work domain where a driver can safely act in. By visualizing the future trajectory, for given steering input, together with the physical limitations of the vehicle, it has been shown that an improved task execution, reduced control activity and less conflicts with the controller occurred [22]. By showing the range of possibilities in a dynamic driving scenario, the driver can obtain an improved understanding towards HSC intended trajectory, as it lies in the range of possibilities. However, the design approach of EID is partly in conflict with HSC design approach. Where EID encourages drivers to either perform their own driving style, or to follow visualised trajectory, HSC is an optimising strategy where it wants drivers to follow one specific 'optimal' trajectory. This visualisation method has a satisficing origin. Research should show what the impact is of this visualisation method on terms of conflicts, and why these conflicts occur.

The aim of this study is to analyse the effect of complementing a single trajectory based Haptic Shared Controller with two types of visual feedback, an optimising strategy and a satisficing strategy, on driving behaviour. In particular, this study evaluates the effect of these feedback conditions on control conflicts during two types of overtake strategies initiated by HSC, an early overtake and a late overtake. For both overtake strategies, it was hypothesized that driving with HSC in combination with visualizing its intended trajectory leads to reduced control conflicts, as drivers will become more compliant towards HSC intent. For the newly designed inspired EID, it is hypothesized that two groups will form, one where control conflicts increase, as the driver is more aware of other possibilities, and one where the control conflicts decrease, as participants can follow the trajectory accurately by laying the trend vector over visualised HSC intended trajectory. Moreover, it is expected that providing visual feedback improves acceptance compared to HSC, as drivers can prepare for future actions. In order to evaluate the three feedback conditions following groups of measures are defined; position based conflicts, HSC compliance, and subjective acceptance.

II. VISUAL FEEDBACK DESIGN

A. Ecological Interface Design Philosophy

Ecological Interface Design has been introduced as a framework for complex human-machine systems by Vicente et al. [23]. This framework focuses on transforming a cognitive task into a perceptual one, by providing meaningful information about the available work domain [24]. By means of a top down approach, this domain is reduced by three constraints [25], respectively physical constraints, intentional constraints and automation constraints. In the automotive sector, physical constraints refers to the physical capabilities of a vehicle, intentional constraints to the rules and regulations on the road, and automation constraints to the implementation of e.g. ADAS. By designing a visual feedback display, using EID principles, drivers are able to perceive available work domain, and therefore, are able to form an opinion about e.g. HSC intended trajectory. Designed visual feedback display can be projected on the road through a head-up display.

B. Static Obstacles

In Figure 1 an EID-inspired visual feedback design is shown, designed by Vreugdenhil et al. [22]. By showing the performance envelope, based on maximum yaw limits of a vehicle, the physical constraints are visualised. Moreover, the trend vector, showing future trajectory for current steering input and velocity, is projected. Equation 1 till Equation 4 show the definition of these yaw limits, where R_{arc} is the radius of these yaw rates, based on yaw rate (r_{yaw}) and velocity (v_{car}). Moreover, the length of projection of these yaw limits depends on a look ahead time (t_{ahead}) of $4.5\,\mathrm{s}$.

$$R_{arc} = \frac{v_{car}}{r_{yaw}} \tag{1}$$

$$\delta = \frac{v_{car} \cdot t_{ahead}}{R_{arc}} \tag{2}$$

$$x_{max} = R_{arc} \cdot sin(\delta) \tag{3}$$

$$y_{max} = R_{arc} - R_{arc} \cdot cos(\delta) \tag{4}$$

At last, information about intentional constraints is provided by detection of road boundaries through imaginary toggle points in visualised max yaw limits, set to $2\,\mathrm{s}$. Once such a point exceeds a road boundary, the visualised max yaw limits turns red to warn a driver. This EID-inspired visual feedback design provides information of the available work domain for static obstacles. However, the available work domain changes when driving in a situation with e.g. another moving vehicle, as the velocity of the other vehicle should be taken into account. Therefore, a new EID-inspired visual feedback display will be designed, applicable for overtaking vehicles.

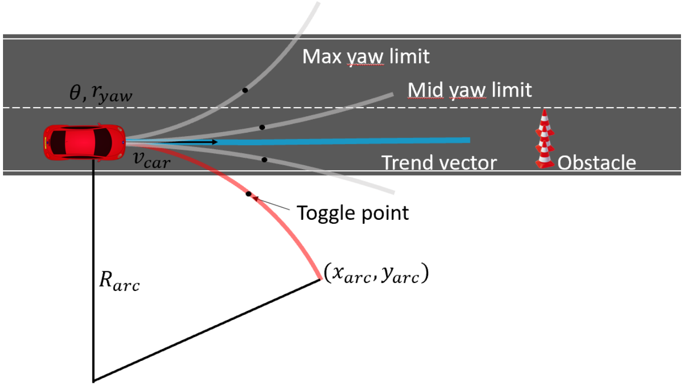

Fig. 1: EID-inspired visual feedback design for static obstacles, designed by Vreugdenhil et al. [22]. Grey lines represent yaw rates, corresponding to physical constraints. These lines can turn red when the invisible toggle point exceeds a round boundary. The trend vector shows the future states for current inputs.

C. Dynamic Obstacles

Here, a first step in the design of an EID-inspired visual feedback applicable for overtaking vehicles is made, by using the three constraints. First the available work domain has been bounded by visualising the manoeuvring boundaries. The manoeuvring boundaries provide information about two states of overtaking, either the latest moment of starting an overtake and the first possible moment of ending an overtake. Information about these states are provided by taking relative velocity into account for visualising the maximum yaw rates, stated in Equation 5 till 8, where t_{ahead} is set to 1 s:

$$R_{arc\_dyn} = \frac{v_{car} - v_{lead\_vehicle}}{r_{yaw}} \tag{5}$$

$$\delta = \frac{(v_{car} - v_{lead\_vehicle}) \cdot t_{ahead}}{R_{arc}} \tag{6}$$

$$x_{max} = R_{arc} \cdot sin(\delta) \tag{7}$$

$$y_{max} = R_{arc} - R_{arc} \cdot cos(\delta) \tag{8}$$

Moreover, the starting point of these yaw rates is adjusted to either the right back, for steering right, or right front, for steering left. By these adjustments, the latest possible moment of steering in order to prevent a collision is visualised by the front yaw rate, where the back yaw rate shows the first possible moment of steering back after an overtake. For intentional and automation constraints, no adjustments are made with respect to the design for static obstacles. Future trajectory for current yaw rate and velocity are depicted by the trend vector, which is updated in real-time. Moreover, the trend vector displays ego car's width, in order to visualise ego car's boundaries. Note that the yaw rate in this design depends on a constant steering wheel input, with which the vehicle remains stable at current velocity. Secondly, intentional information was provided by detection of the road boundaries. When an invisible toggle point in the trend vector, set to a look ahead time of 2 s, exceeds a road boundary, the trend vector will turn red instead of blue. This informs the driver when choosing this trajectory, the lane will be left in less than 2 s. Here, the outermost lane boundaries were chosen for providing intentional information, where the road centre line was not taken into account. At last, automation information is provided by visualising HSC intended trajectory. This trajectory has been defined by recording position data, and using these coordinates as input for both HSC as visuals. Here, the look ahead time is set to 5 s. By visualising HSC intended trajectory, a preview is given, allowing drivers to anticipate on HSC's intent.

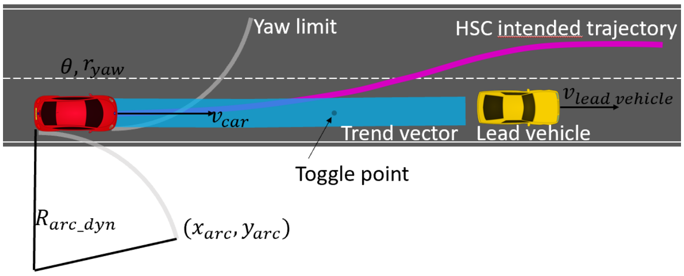

Fig. 2: New EID-inspired visual feedback design applicable for overtaking vehicles. The yaw limit originating from car's right front represents the latest possible moment of steering in order to prevent a collision, where the yaw limit originating from car's right back shows the first possible moment of steering back after an overtake.

III. METHOD

A. Participants

Twenty-four participants (13 women and 11 men) between 19 and 59 years old (M = 27.7 & SD = 9.6) volunteered for the driving simulator experiment without receiving a financial compensation. Participants, all having a normal or corrected to normal vision, had a driver's license for at least one year.

B. Apparatus

The experiment was conducted in a fixed-base driving simulator at the Control and Simulation Department of Aerospace Engineering, Delft University of Technology, shown in Figure 4. The scene was visualised on the wall with a horizontal view of 180° and a vertical view of 40°. To facilitate perception of the car's relative position on the road, the front of the car was visualised. The visuals were updated at a rate of $50\,\mathrm{Hz}$. The driving simulator was equipped with an actuated steering wheel, actuated by the Moog-FCS S-motor, used to provide the driver with haptic steering guidance. This actuator was updated at a frequency of $2500\,\mathrm{Hz}$. The simulation data was logged at a rate of $100\,\mathrm{Hz}$. A sedan of $1.8\,\mathrm{m}$ width was used to simulate the vehicle, having a maximum yaw rate of 0.33.

C. Haptic Steering Guidance

For the control algorithm of HSC the Four Design Choice Architecture (FDCA) has been used [26], consisting of (1) Human Compatible Reference (HCR), (2) Strength of Haptic Feedback (SoHF), (3) Level of Haptic Support (LoHS), and (4) Level of Haptic Authority (LoHA). In this particular study, LoHA is not implemented, resulting in nominal steering wheel stiffness of $1.7\,\mathrm{N\,m}$. In Figure 3 a schematic overview of used control algorithm, based on Four-Design-Choice Controller, can be found.

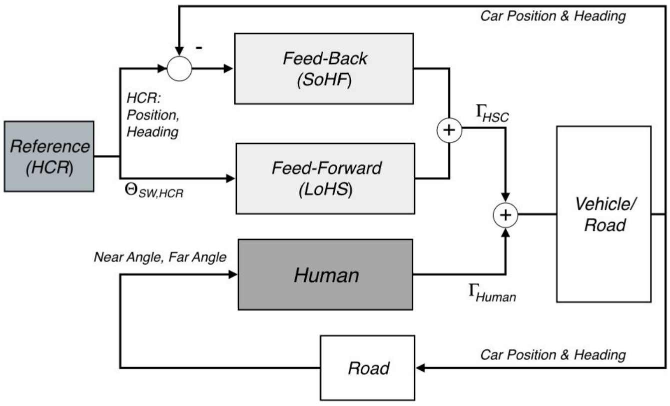

Fig. 3: Schematic overview of used control algorithm, based on Four-Design-Choice Architecture [14].

The HCR, containing vehicle position (X and Y), heading and steering wheel input is generated by manually driving the simulated track and recording required data. Averaging three recorded data-sets, driven on the right lane, and pasting in two overtake strategies, resulted in the final HSC input. An example of recorded position input is shown in Figure 6, where the experimental HCR's are depicted in terms of position.

The Strength of Haptic Feedback (SoHF) aims to correct for deviations from HCR heading input ($\Delta\psi$) and position input (Δy) by means of feedback torques. The strength of these torques can be tuned with K_ψ, K_y and K_{FB}. In Equation 9 the definition of SoHF is depicted.

$$SoHF = K_{FB} \cdot (K_\psi \cdot \Delta\psi + K_y \cdot \Delta y) \tag{9}$$

The Level of Haptic Support (LoHS) provides feed-forward torques by means of HCR's steering input. Again, the strength of these torques can be tuned by K_{FFW}. Equation 10 shows the definition of LoHS.

$$LoHS = K_{FFW} \cdot \Theta_{HCR} \tag{10}$$

Chosen tuning for this research can be found in Table I.

TABLE I: Control parameters of FDCA

Gain	FDCA
K_y	0.05
K_ψ	0.03
K_{FB}	1.2
K_{FFW}	0.36

Fig. 4: Overview of designed visual systems from driver's perspective. Where purple line displays HCR (controllers trajectory), blue area the trend vector, and grey light line the yaw limits which indicate latest time moment of steering to prevent a collision. First visual system consists of HCR only, where second visual system contains all visuals.

D. Experimental Design

Three feedback systems were evaluated in a within-subject repeated-measures design, in order to test the effect of complementing HSC with different types of visualisation. All participants drove with 1) HSC not complemented with visual information, 2) HSC complemented with visualised HSC intended trajectory, 3) HSC complemented with visualised HSC intended trajectory and vehicle's manoeuvring boundaries, in a counterbalanced order. In order to get familiar with the simulator and feedback systems, a training session was performed, provided in generic order.

Participants drove all trials on the same trajectory, being a two-lane road of $21.1\,\mathrm{km}$ long with a lane-width of $3.6\,\mathrm{m}$. The road consisted out of straight sections, followed by two curves in opposing direction, each having an inner radii of $400\,\mathrm{m}$, see Figure 5. The driving speed was fixed at $100\,\mathrm{km\,h^{-1}}$. On the straight sections other vehicles, with a length of $3\,\mathrm{m}$ and width of $1.8\,\mathrm{m}$, were driving in the middle of the right lane with a speed of $80\,\mathrm{km\,h^{-1}}$.

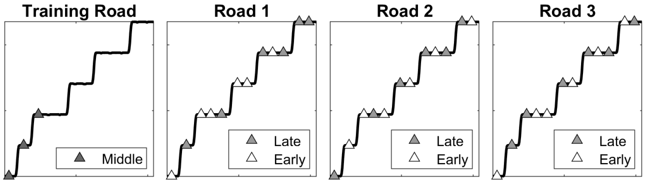

Fig. 5: Overview of designed track, all containing six early overtake manoeuvres and six late overtake manoeuvres. Here, the ratio between x and y axis is 20:1 to better visualise the existence of curvatures.

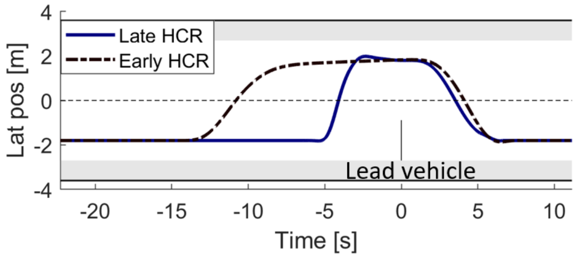

Fig. 6: Trajectories used as input for HSC and visuals during experimental trials.

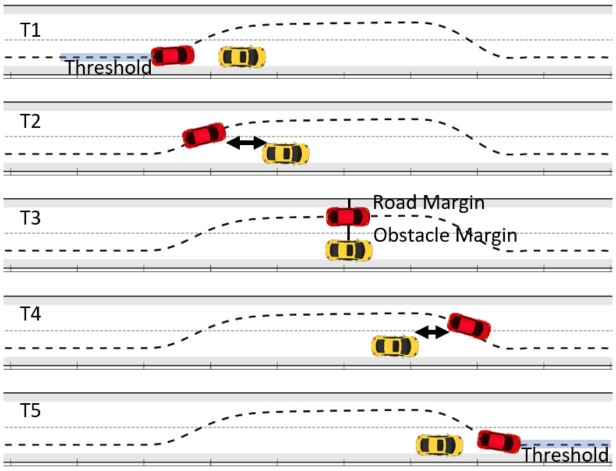

Fig. 7: Schematic overview of dependent measures, T_1 is the starting moment of the overtake, when vehicle exceeds threshold, T_2 is minimum time to collision, T_3 defines road margin and obstacle margin when cars are parallel, T_4 is minimum time to collision when steering back to right lane, T_5 is end moment of overtake, defined as first moment when car is back in defined threshold.

The speed difference between ego car and lead vehicle, forced the occurrence of an overtake manoeuvre in order to prevent a collision. During the experimental trials, HSC initiated an overtake at different time moments, see Figure 6:

1) An early overtake, starting $12.5\,\mathrm{s}$ before collision
2) An late overtake, starting $4.7\,\mathrm{s}$ before collision

For the training session, however, the overtake started at $7.3\,\mathrm{s}$ before collision. During the training session, three overtakes were practiced. Where during the main trials, six early overtakes and six late overtakes took place. To overcome anticipatory behaviour by learning the order, three different obstacle orders were designed, see Figure 5.

E. Procedure and instructions

Prior to the driving study, participants read and signed an informed consent form, providing information about the goal, the procedure, and the risks of the study. Moreover, participants filled in a Driving behaviour Questionnaire (DBQ), consisting questions about driver's driving behaviour and their experience with automated driving functions. Next, participants were requested to take place in the driving simulator and adjust the seat according to their preferences. While seated, all conditions were explained one more time. Afterwards, the training session started, making the participant familiar with the driving simulator and feedback modalities.

After familiarization, the experiment started, where the controller initiated two different overtakes. The participant was instructed to drive as it normally would with given feedback system, meaning that it could overrule it or agree with it. When a trial had been finished, the participant filled in the Van Der Laan (VDL) questionnaire [27] to obtain subjective usefulness & satisfaction. Additional questions were asked regarding amount of feedback provided, time moment of overtaking and trust towards the controller.

The total experiment, including filling out questionnaires and training, took approximately 1 hour and 15 minutes per participant.

F. Dependent measures

During the experiment raw data was logged. In order to analyse conflicts between driver and controller different measures are defined, divided in three groups; position based measures, HSC compliance, and subjective based measures.

1) Position based measures: In order to analyse driving behaviour of participants during an overtake, five different time moments of an overtake are defined. By comparing HSC intended trajectory and participants driven trajectory on these time moments, an indication for position based conflicts can be gathered:

- *Longitudinal distance w.r.t. lead vehicle at T1:* The start position of an overtake manoeuvre shows the driving preference of a participant. The start of an overtake manoeuvre, at T1, is defined as the first moment when:

$$y_{ego} > (y_{offset} + 0.4) \tag{11}$$

and

$$\psi > 0.3 \cdot max(\psi) \tag{12}$$

and

$$d\psi > 0 \tag{13}$$

Where ψ is heading angle of the vehicle, ψ_{max} is maximum heading reached during overtake, $d\psi$ the derivative of heading, and y_{offset} is middle of the right lane on the road. Moreover, chosen values are heuristically tuned.

- *Longitudinal distance w.r.t. lead vehicle at minimum TTC:* The distance between lead vehicle and ego car for smallest time to collision (TTC), defined as T2, represents experienced situational criticality, and therefore serves as a safety measure. The smaller the value, the more critical the situation [28].
- *Lateral Obstacle Margin & Lateral Road Margin:* The distance between ego car and lead vehicle (Obstacle Margin), and the distance between ego car and road boundaries (Road Margin), when cars are parallel (T3), is a safety indication [28]. Obstacle Margin & Road Margin are antagonistic values, indicating that the safest option is when ego car is in the middle of left lane. This measure will not be analysed compared to controller's value.
- *Longitudinal distance w.r.t. lead vehicle at T4:* Similar measure as 'Longitudinal distance w.r.t. lead vehicle at minimum TTC', where the difference can be found in position of both cars at T4. Here ego car is ahead of lead vehicle [28]. Note that in this specific experiment no collision will occur due to fixed speeds of both cars, however, it provides an indication when steering back to right lane.
- *Longitudinal distance w.r.t. lead vehicle at T5:* The end position, at T5, of an overtake manoeuvre gives a similar indication as the start position. The end of an overtake manoeuvre is defined being the first moment when ego car is back in defined bounds, Equation 11 till 13.

2) HSC compliance: In order to analyse the compliance of drivers towards HSC intended trajectory, occurring torques on the steering wheel are analysed. Figure 8 illustrates different segments where torque has been analysed:

- *Total amount of conflicting torque:* Measuring the total amount of conflicting torque between T0 till T6, gives an indication in what overtake type participants are prone to be more compliant.

$$T_{total} = \int_{T_0}^{T_6} |T_{controller} - T_{participant}| \tag{14}$$

  Here T_0 is defined as $700\,\mathrm{m}$ relative to lead vehicle. And T_6 is defined as $300\,\mathrm{m}$ after lead vehicle.
- *Conflicts in Torque:* By calculating total amount of torque between defined time moments, it can be seen where conflicts occur and in what amount. In Figure 8 defined segments can be found, based on controller's desired trajectory based time moments calculated with position based measures (T0 - T1, T1 - T3, T3 - T5, T5 - T6). Total amount of torque in each segment is calculated in same way as defined in Equation 14, where integral bounds are adjusted to time bounds.
- *Maximum absolute difference in torque:* The maximum value of absolute difference in torque between participant and controller shows amount of conflict one is tended to give.

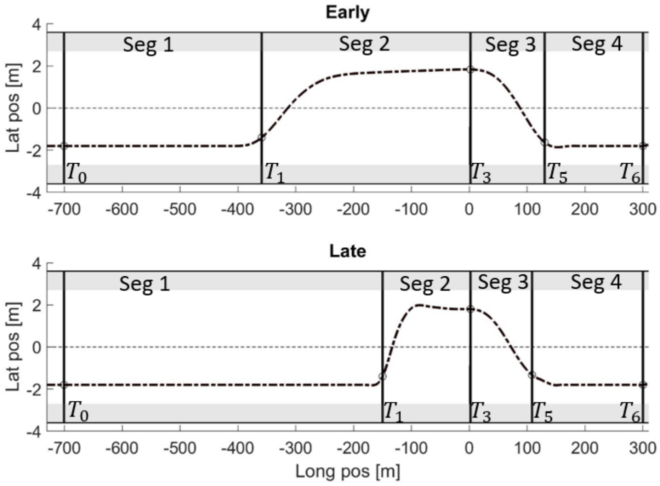

Fig. 8: Defined segments for analysing HSC compliance. Segments are based on calculated time moments of controller's trajectory based on position based measures, where T_0 and T_6 are added.

3) Subjective based measures:

- *Van Der Laan Questionnaire:* Van Der Laan questionnaire has been developed to asses the acceptance of a system, which uses two scales; usefulness and satisfaction [27].

G. Statistical analysis

For all dependent measures a matrix of 24 participants x 6 conditions was obtained. The 6 conditions were formed by two independent variables, being feedback type (visuals) and overtake manoeuvre type. To correct for non-normal distributions and unequal variances, the matrix was transformed in ranks [29]. This corrected matrix was used as input for an analysis of variance (ANOVA) with 2x3 conditions as within-subject factor, to verify the overall significance between all driving conditions for all measures. An exception has been made for HSC compliance measures, here an one-way analysis of variance was used, as segments defined for overtake types differ from each other.

IV. RESULTS

This section presents the experimental results based on defined measures for two different overtake strategies, and three different feedback conditions. The combination of overtake strategies and feedback conditions led to six different data-sets. In Table II the mean, standard deviation and results of 2x3 repeated measures ANOVA and its pairwise comparison are shown for defined measures. An exception is made for results concerning torque in defined segments, which is presented in Table III, where an one-way ANOVA is performed. Here, striking results for all measures will be interpreted separately for driving with different feedback conditions.

TABLE II: Means (M), standard deviations (SD), and results of the 2x3 repeated measures ANOVA per dependent measure. Here, - in pairwise comparison indicates no significant effect between chosen pairs.

		HSC (1)		REF (2)		EID (3)				Pairwise comparison					
										Early			Late		
		Early	Late	Early	Late	Early	Late	F(138,2)	p-value	1-2	1-3	2-3	1-2	1-3	2-3
Longitudinal diff. at T1	M	18.534	-100.367	24.709	-95.725	15.023	-94.408	0.080	.924	-	-	-	-	-	-
	SD	67.928	92.161	42.601	88.805	89.632	83.252								
Longitudinal diff. at T2	M	23.680	-62.668	32.073	-59.706	25.660	-58.132	0.270	.766	-	-	-	-	-	-
	SD	67.598	75.852	53.598	72.542	70.793	68.456								
Longitudinal diff. at T4	M	-4.196	3.352	-7.404	-0.443	-6.357	1.854	0.690	.505	-	-	-	-	-	-
	SD	18.005	22.754	18.159	20.042	21.520	21.495								
Longitudinal diff. at T5	M	3.9161	14.691	-2.851	9.833	-1.917	13.483	0.400	.674	-	-	-	-	-	-
	SD	29.054	32.118	18.096	26.269	25.748	29.075								
Road Margin	M	1.048	1.078	1.072	1.093	1.054	1.122	0.280	.760	-	-	-	-	-	-
	SD	0.179	0.248	0.269	0.244	0.247	0.235								
Obstacle Margin	M	1.652	1.623	1.628	1.608	1.646	1.578	0.280	.760	-	-	-	-	-	-
	SD	0.179	0.248	0.269	0.244	0.247	0.235								
Total torque	M	725.272	752.434	682.048	755.120	673.373	691.595	0.580	.561	-	-	-	-	-	-
	SD	374.103	293.868	409.688	323.191	355.110	256.488								
Max torque	M	2.474	3.794	2.214	3.714	2.209	3.366	1.500	.227	-	-	-	-	-	-
	SD	1.290	0.654	1.267	0.794	1.125	0.742								
VDL usefulness	M	0.183	-0.117	0.442	0.075	0.608	0.208	3.660	.028	-	-	-	-	-	-
	SD	0.683	0.715	0.490	0.823	0.576	0.959								
VDL satisfaction	M	0.240	-0.823	0.604	-0.521	0.781	-0.375	4.420	.014	-	-	-	-	-	-
	SD	1.020	0.799	0.847	0.773	0.518	1.068								

TABLE III: Means (M), standard deviations (SD), and results of the one-way ANOVA per dependent measure. Here, - in pairwise comparison indicates no significant effect between chosen pairs.

			HSC (1)	REF (2)	EID (3)			Pairwise comparison		
						F(138,2)	p-value	1-2	1-3	2-3
Segment 1	Early	M	195.984	160.117	172.009	0.090	.914	-	-	-
		SD	132.456	87.020	90.319					
	Late	M	473.880	482.213	433.339	0.270	.768	-	-	-
		SD	303.589	296.586	257.304					
Segment 2	Early	M	352.491	336.538	338.306	0.070	.932	-	-	-
		SD	276.241	279.449	260.309					
	Late	M	101.094	103.144	97.947	0.120	.890	-	-	-
		SD	46.690	43.063	37.880					
Segment 3	Early	M	103.546	105.962	100.424	0.450	.637	-	-	-
		SD	64.345	71.467	76.255					
	Late	M	97.971	88.460	90.699	0.120	.891	-	-	-
		SD	58.800	51.926	48.139					
Segment 4	Early	M	73.251	79.432	62.635	0.660	.518	-	-	-
		SD	33.677	41.623	24.618					
	Late	M	79.490	81.296	69.610	0.930	.399	-	-	-
		SD	30.442	31.655	24.459					

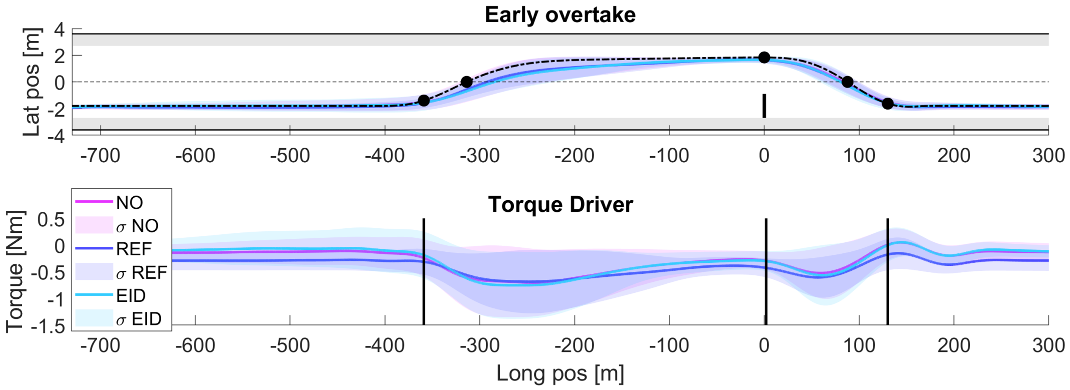

Fig. 9: Mean & SD of all driven trajectories for each feedback condition w.r.t. HSC early intended trajectory with corresponding driver torque. The dots represent time instances by position based measures.

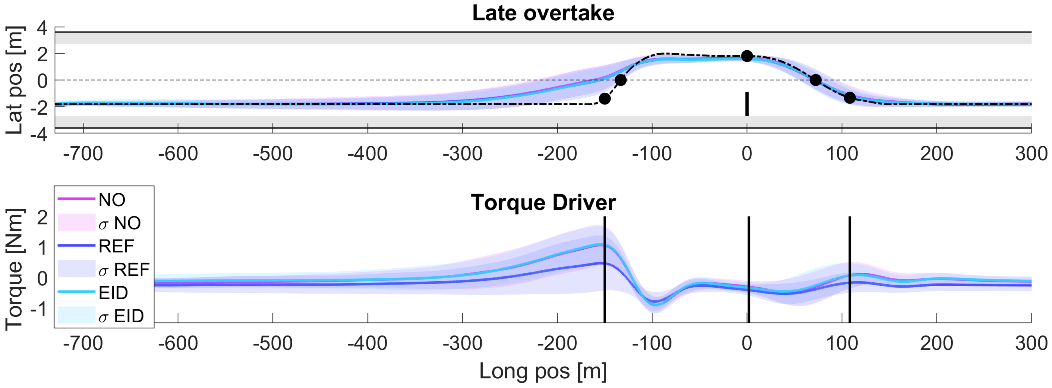

Fig. 10: Mean & SD of all driven trajectories for each feedback condition w.r.t. HSC late intended trajectory with corresponding driver torque. The dots represent time instances by position based measures.

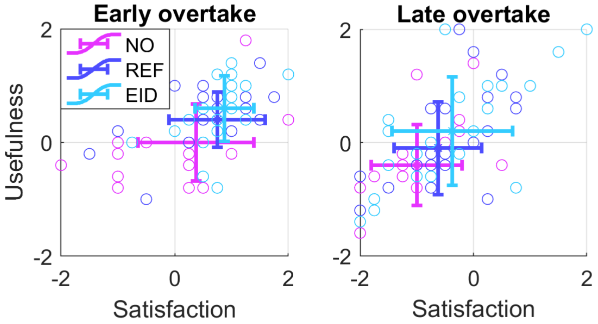

Fig. 11: Outcomes of van Der Laan questionnaire shown in error bars for all feedback conditions. Early overtake has been rated more positively compared to late overtake. Where same trend is found in terms of driven conditions.

A. *Feedback conditions*

Figure 9 and 10 show the mean and standard deviation for all driven data for three conditions and two strategies and corresponding driver torque. No significant effect between all feedback conditions for both overtake strategies is found for position based measures and torque based measures, see Table II and III. Analysing Van Der Laan questionnaire, however, shows a significant effect in terms of usefulness ($p<0.05$) and satisfaction ($p<0.02$) between the feedback conditions. However, pairwise comparison did not result in significant effects.

Either visualising HSC intended trajectory, as complementing it with visualisation of the vehicle its manoeuvring boundaries, did not result in a compatible behaviour between participants and HSC intended trajectory on group level, see Figure 9 and 10. However, Figure 12 suggests that, on within-subject level, participants adapt their behaviour when driving with different visualisation systems. Therefore, a subsequent analysis will be performed to further analyse this.

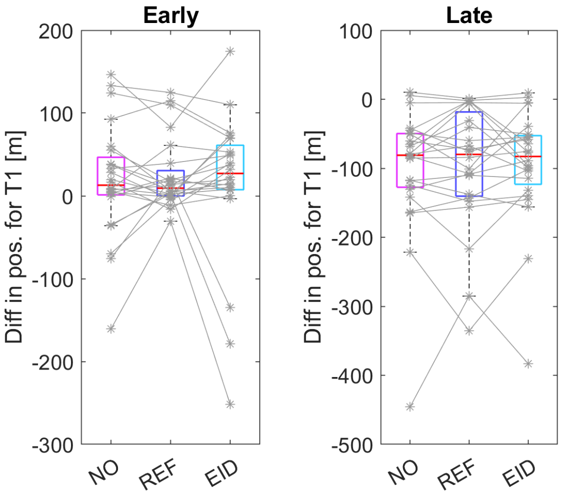

Fig. 12: Starting time of driver with respect to HSC intended starting time for three feedback conditions, both early and late. Where a negative value means steering earlier and positive value means steering later than HSC.

B. *Subsequent analysis*

As no significant effects for defined dependent measures are found between designed feedback systems, a subsequent analysis is performed in order to find a possible explanation for this. This is done by analysing position based data on within-subject and between-subject level for HSC intended early overtake. Afterwards, it is evaluated if there is a correlation existing between position based measures and outcomes of Van Der Laan questionnaire.

1) Groups: From analysing position data, it can be found that participants are either following, steering earlier, or steering later than HSC intended trajectory. This distinction is made by comparing participant's driven trajectories with HSC intended trajectory, and based on the difference with respect to HSC intended trajectory decide what driving behaviour the participant is performing (following, earlier, later). In Table IV the number of participants with corresponding behaviour for different feedback systems is stated. This shows that visualising HSC intended trajectory results in more followers compared to no visuals or visualising manoeuvring boundaries.

TABLE IV: Number of participants following or fighting a system, both earlier and later, for each feedback condition.

		Following	Earlier	Later
# Participants	No visuals	10	4	10
	REF	18	0	6
	EID	11	3	10

Figure 13 shows different types of driving behaviour for feedback systems, based on within-subject analysis. This figure suggests that four groups exists, where 1) participants are fighting HSC intended trajectory for all feedback systems, 2) participants are following HSC intended trajectory for all feedback systems, 3) participants are fighting HSC intended trajectory when driving with inspired-EID, 4) participants are fighting when driving without visuals. Here, fighting can be either steering earlier or steering later with respect to HSC intended trajectory. Moreover, data of three participants was excluded as they did not show any consistent behaviour, respectively participant 5, 8 and 14.

2) Van Der Laan Questionnaire: As subsequent analysis suggests the existence of four groups of behaviour by objective behaviour, another analysis is performed by combining this with the outcomes of Van Der Laan Questionnaires. In Figure 14 it can be seen that 'Followers' and 'Fighters' prefer driving with either type of visual information. Where participants fighting for at least one visualisation system prefer driving with inspired-EID.

V. DISCUSSION

A driving simulator study was conducted to investigate the effect of supporting HSC with two different visual feedback systems on driving behaviour, compared to driving with HSC without visuals. This section discusses results found with its focus on predefined hypotheses. Additionally, study limitations and recommendations for future work are provided in this section.

A. Feedback conditions

Contrarily to predefined hypotheses, results indicate no significant effect between driven feedback conditions for both HSC intended early or late overtake on group level, where all driven feedback conditions vary from HSC intended trajectory. Nonetheless, visual information caused an improved rating in both usefulness and satisfaction. From subsequent analysis, it could be argued that this non-significant effect is caused by averaging over multiple driving patterns, being following HSC intended trajectory, or steering earlier/later compared to HSC intended trajectory. Within-subject analysis even suggests the existence of four groups of driving behaviour, based on change in behaviour for the different feedback condition. These groups are 1) fighting for all feedback conditions, 2) following for all feedback conditions, 3) fighting for driving without visual

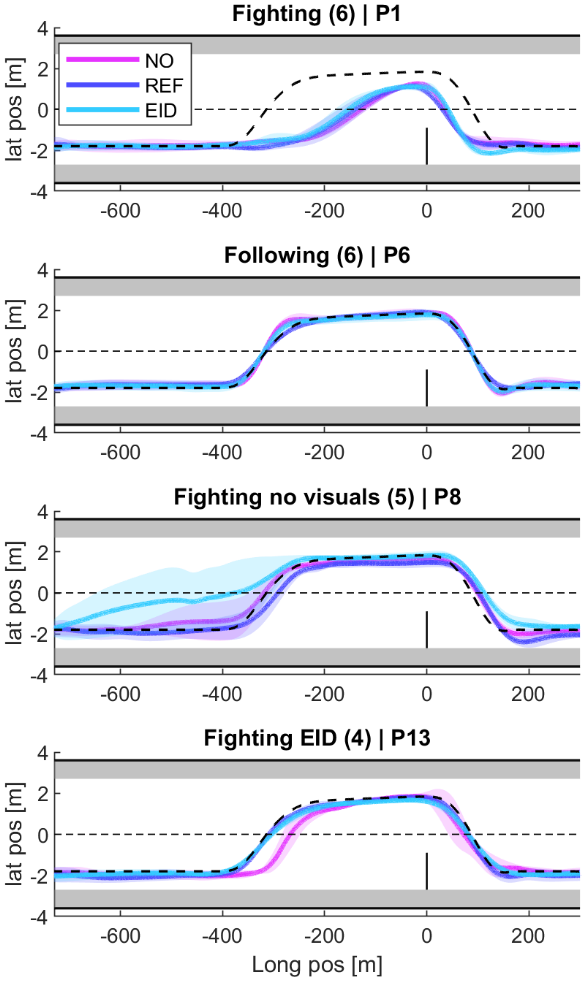

Fig. 13: Examples of driven trajectories by typical participants, and the number of participants in these groups. These examples show the existence of multiple groups, where Participant 1 shows fighting behaviour for all conditions, Participant 6 shows following behaviour for all conditions, Participant 8 shows following behaviour for no visuals and HSC conditions, where it is fighting EID. Participant 13 shows following behaviour for driving with visuals, where fighting occurs for no visuals.

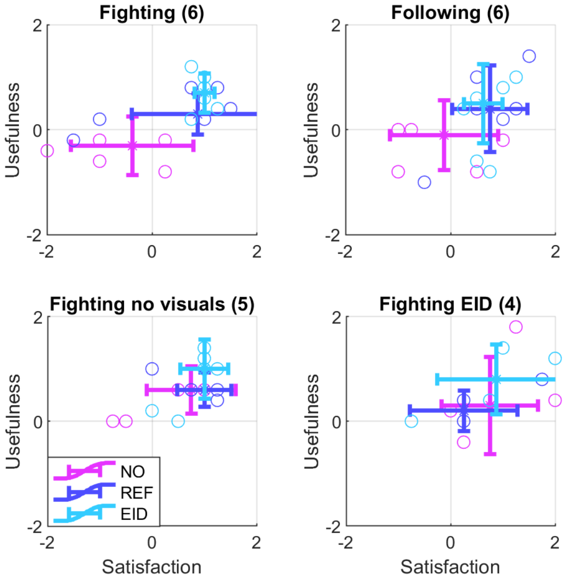

Fig. 14: Outcomes of van Der Laan questionnaire for defined groups. Where followers and fighters are showing a preference for driving with visuals, and fighting HSC or EID show a preference for EID-inspired visuals.

information, 4) fighting with EID-inspired visual feedback. The existence of these groups is possibly related to initial compatibility between driver and HSC intended trajectory, initial acknowledgement of innovative ADAS, understanding and trust towards HSC intended trajectory, and willingness to adjust initial behaviour towards HSC intended trajectory. For example, first group shows fighting behaviour for all driven feedback conditions. This indicates that participants push through their own driving behaviour, which is possibly caused by a difference in initial compatibility between driver and HSC intended trajectory, and the non-willingness to become more compatible. Second group, showing following behaviour for all driven feedback conditions, could be caused by an initial compatible behaviour, but at the same time it could indicate a willingness of participant to adjust their initial behaviour towards HSC intended trajectory. For third group, fighting for driving without visual information, it could be suggested that this group is willing to follow HSC intended trajectory, but only when participants know future intent beforehand. This shows that HSC without visuals is not providing enough information [11] [12]. At last, the fourth group, fighting when driving with EID-inspired visual feedback, suggest that participants are prone to follow HSC intended trajectory, however, EID-inspired visual feedback provides the driver with other possibilities, leading to non-compatible behaviour. This group also shows an improved satisfaction and usefulness for EID-inspired visual feedback over other two feedback systems. This indicates that participants feel encouraged to perform own strategy, and do not feel obligated to follow HSC intended trajectory. This driving behaviour is possibly caused by the satisficing design principle of EID-inspired visual feedback [24].

The non-significant effect on group level, therefore, does not necessarily mean that these feedback systems do not influence the driving behaviour of one participant. More interestingly, it even suggests that more participants become compliant when visualising HSC intended trajectory, with exception of participants fighting for all feedback conditions. Moreover, driving with EID-inspired visual feedback shows the existence of both followers as fighters. This indicates that both optimising and satisficing visual design strategies show on within-subject level hypothesized effects. Remarkably, all participants preferred driving with visual information, shown by an improved satisfaction and usefulness. This could imply that, for both fighters as followers, participants prefer knowing future intent, and therefore prepare for future actions of HSC.

B. *Limitations*

The first limitation in this study concerns the design of the road environment. Driving on a two-lane road, with fixed speed, and a maximum of one other car on the road, made the overtake task relatively simple and predictable. To improve the effect of complementing HSC with visual information, and the effect of different types of visual information, more complex road conditions should be designed. With an increased complexity, the effects of fighting with EID-inspired visual feedback design will possibly increase, as drivers see other opportunities compared to HSC intended trajectory.

Another limitation concerns the visualisation method of projecting HSC intended trajectory on the road. In this simulator study, HSC intended trajectory was predefined, meaning that it does not take into account the position of the other vehicles on the road. Where HSC planned to initiate an overtake with a specific time with respect to lead vehicle, visuals did only show similar information. Especially, in visualisation of the late overtake, the lead vehicle was driving for longer time on HSC intended trajectory. This could influence the driving behaviour of participants. In order to overcome this issue, another way of visualising HSC intended trajectory should be designed, where the dynamics of the lead vehicle are taken into account. This adjustment in visualisation also brings the need of adapting HSC input to one which takes the lead vehicle into account.

Last limitation has to do with the definition of suggested groups, based on within and between subject analysis. Here, the order of conditions provided to participants are not taken into account, meaning that training effects, and change in behaviour due to boredom, are not taken into account. However, these suggested groups still can be used as preliminary study.

C. *Future work*

From findings of this research, recommendations for future work can be given. After suggesting the existence of four groups of behaviour for provided feedback systems, based on within-subject level, first recommendation is directed to further investigate the origin and behaviour of these groups. Finding out the real reason of performed behaviour, e.g. willingness to adjust driving behaviour or initial compatibility, could improve our understanding of the origin of these groups. Mainly on higher level this information could be useful.

Another recommendation concerns the design of EID-inspired visual feedback. In this study, EID-inspired visual feedback was specifically designed for overtaking vehicles. However, the research of Vreugdenhil et al. [22] showed promising results of complementing HSC with EID-inspired visual feedback for avoiding static obstacles. As both studies showed an improved rating in both satisfaction and usefulness of complementing HSC with EID-inspired design, it is recommended to design a new EID-inspired visual feedback which can be used for both static and dynamic obstacles. This new design fits better in driving in normal road conditions, where both static and dynamic, with different velocities, vehicles exist.

Moreover, where this study complements a single trajectory based HSC with EID-inspired visual feedback, another recommendation to research is adjusting HSC's implementation from an optimising strategy to a satisficing one. For example, Tsoi et al. [30] designed a haptic guidance system for overtakes, which is activated when a driver exceeds a certain threshold by steering. In order to keep HSC's benefits, faster reaction times for critical situations [31] [22], it is suggested to force the latest moment of steering for preventing a collision by HSC. Note that this is in line with HSC manoeuvring boundaries. This design approach probably reduces control conflicts between driver and HSC intent. At last, it is recommended to further investigate the effect of visualising HSC intended trajectory and complementing this with visualising manoeuvring boundaries on intra-driver variability during an overtake manoeuvre. As Yao et al. [32] pointed out that one participant shows variability in his/her performance of an overtake, it is recommended to research whether this variability decreases when supporting the driver with HSC and visual information.

VI. CONCLUSION

This study presents the results of complementing HSC with visual information during overtake scenarios, where one visualisation shows HSC intended trajectory, whereas the other complements this by showing the manoeuvring boundaries of the vehicle. Although, from a human-in-the-loop experiment, participants reported a preference for the EID-inspired visuals, no significant effects between driven feedback conditions are found:

- Position based measures do not show significant effects between driven feedback conditions over multiple time instances during an overtake.
- No significant effect in terms of compliance towards HSC has been found over whole driven trajectory, and over multiple segments, between driven feedback conditions.
- Visualising HSC intended trajectory improved user acceptance, whereas EID-inspired visuals shows an higher improvement.

A subsequent analysis showed multiple existing behaviour for the different feedback conditions, explaining the non-significance on group level between these feedback conditions. From subsequent analysis following trends are suggested:

- Visualising HSC intended trajectory leads to an improved compatibility of HSC, as more participants were prone to follow HSC intended trajectory compared to no visuals and EID-inspired visuals.
- Visualising HSC intended trajectory, complemented with the manoeuvring boundaries of the car, showed the existence of two groups of behaviour. First group was prone to follow HSC intended trajectory, whereas the other group showed a non-compatible behaviour.
- Participants showing non-compatible behaviour for at least one condition slightly prefer driving with inspired-EID, where participants showing compatible behaviour prefer driving with either one of the visualisation strategies.

This research suggests that supporting HSC with visual information does not improve the compatibility between driver and HSC's intent, but shows an improvement in acceptance. Future research should further investigate the effect of these visualisations types on intra-driver variability. Moreover, it is recommended to investigate the impact on compatibility when combining an EID-inspired visual feedback design with a compliant HSC, where a driver initiates the overtake and HSC supports this.

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A

Road design & HSC design

ROAD DESIGN

To be able to perform a driver study in the driving simulator at the HMI Lab of Delft University of Technology, a road should be designed. In this study focused on the effect of control conflicts for driving with different feedback systems during an overtake manoeuvre . Therefore, the road should be designed accordingly, so that other vehicles could be overtaken.

The design of the road was constrained by the capabilities of DUECA (Delft University Environment for Communication and Activation), as the movement of lead vehicles was easiest in either northern or eastern direction. Therefore, the road was designed pointing in northern direction, with two opposing curves for variation. Moreover, the designed track was a two-lane road, where the width of one lane was 3.6m. Overtakes all occurred in northern direction. Figure 1 and Figure 2 depict designed road and its curvature profile. On straight sections of the road overtake manoeuvres will occur.

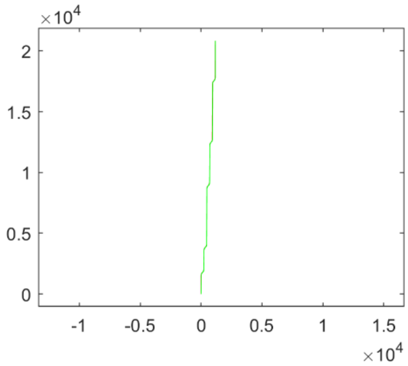


Figure 1: Road design

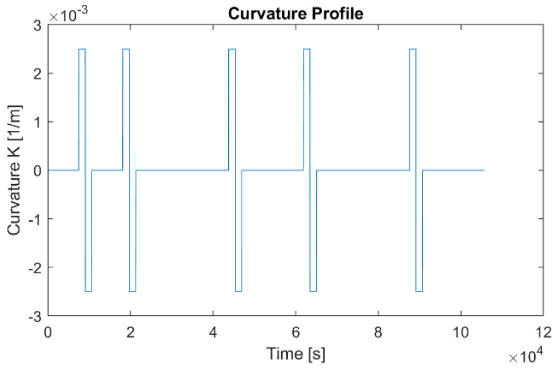


Figure 2: Road curvature

HAPTIC FEEDBACK DESIGN

In this study Haptic Shared Control has been used, to be more specific the Four-Design-Choice Controller. In Figure 1 this controller has been designed schematically. It can be seen that the controller consists out of (1) Human Compatible Reference, (2) Strength of Haptic Feedback, (3) Level of Haptic Support and (4) Level of Haptic Authority. The input for the controller consists out of four data columns, respectively the lateral and longitudinal position (HCR position), the heading of the vehicle and the steering input.

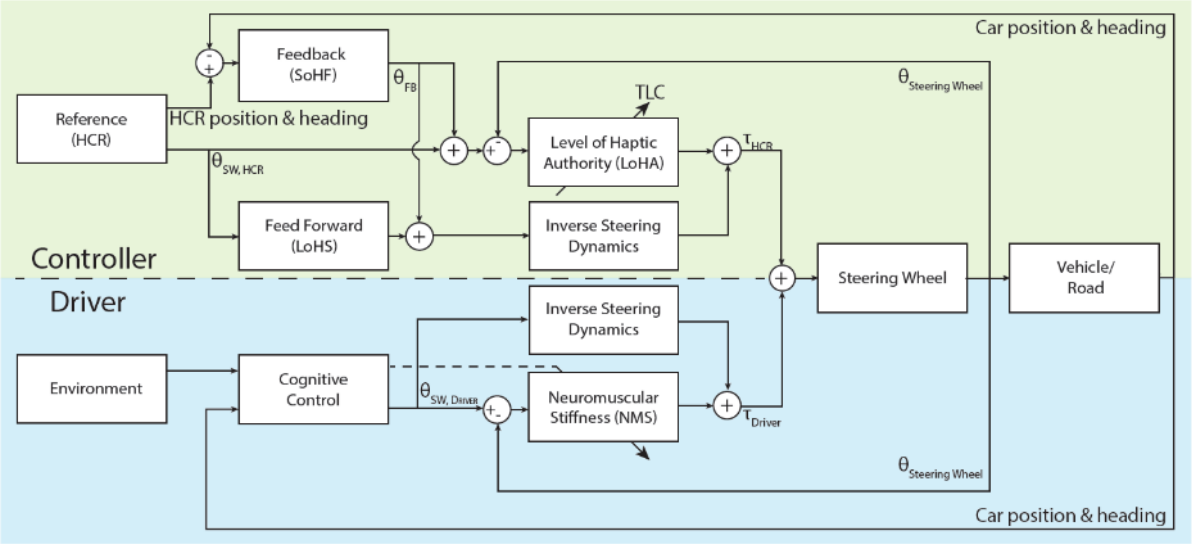


Figure 3: Schematic Overview of the Four-Design-Choice Controller

HUMAN COMPATIBLE REFERENCE

To generate an HCR compatible for this research, different datasets have been driven and recorded. The first dataset contains data of the whole road, where there is continuously driven on the right side of the lane. The other two datasets are overtake manoeuvres, both early and late. These overtake manoeuvres are pasted into the original dataset, so that obstacles on the road are in all cases avoided at the same way. The datasets consist out of four rows, respectively position (X_R,Y_R), vehicle heading (Ψ_R) and steering wheel input (δ_R).

DATASET WHOLE ROAD

The first dataset, containing data of whole road, has been driven three times, and averaged. In Figure 2 the outcome of the averaged road can be found.

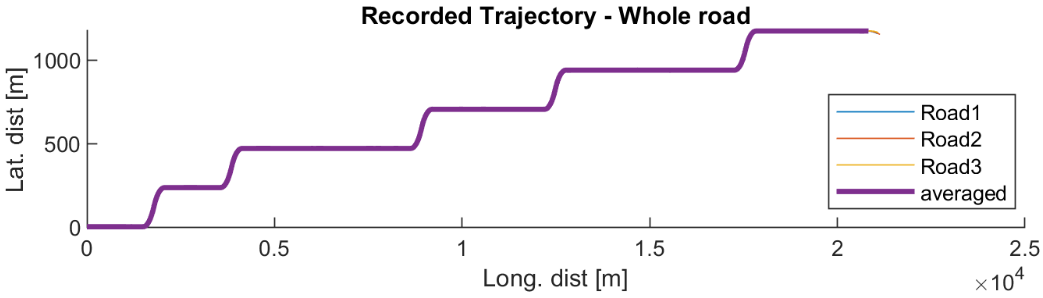


Figure 4: Overview of the road in terms of longitudinal and lateral distance

The same has been done for the vehicle heading and steering input. However, as the datasets contain high frequency noise, which is removed by filtering. Figure 3 and Figure 4 show the heading and steering input over this trajectory. Moreover, the simulator requires an input every 0.2 meters, where recorded data has been recorded with a frequency of 100 Hz and a velocity of 100 km/hr, resulting in a distance of 0.2778 between datapoints. Therefore the dataset is interpolated for all inputs.

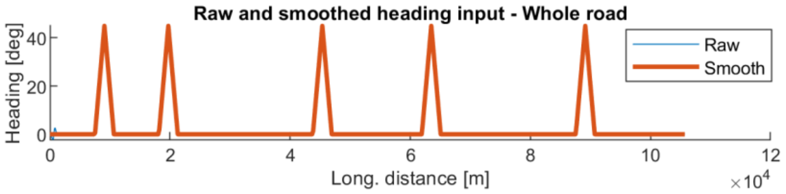


Figure 5: Overview of the heading of the car on the road after filtering data

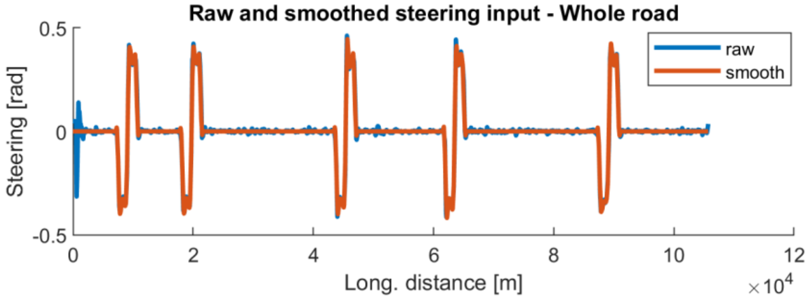


Figure 6: Overview of steering input on whole road after filtering

DATASETS OVERTAKE MANOEUVRES

As this study requires two overtake strategies, an early and a late one, these trajectories are again defined by recording driving data, in this case 1 dataset per overtake. Figure 3 depicts the overtakes used in the experiment, moreover, a middle overtake strategy is defined for the training sessions. Again, high frequency noise is filtered and the data-sets are interpolated. Afterwards, the datasets are pasted on the right positions in the dataset of the whole road.

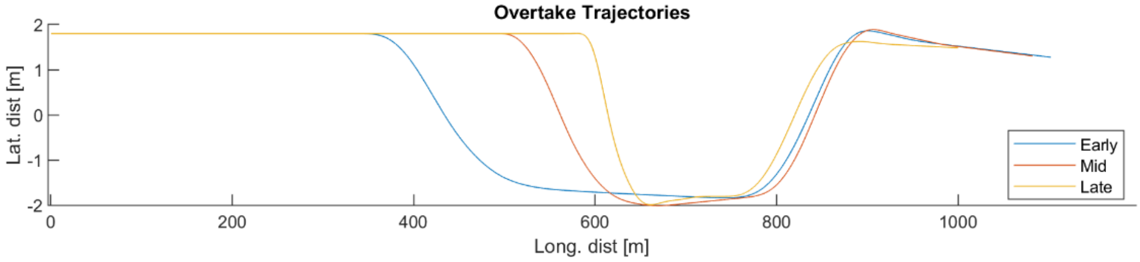


Figure 3: Selected overtakes. Note that sign convention for lateral direction in HMI Lab is in opposite direction.

PASTING OVERTAKE MANOEUVRES IN DATASET

Last step in defining the HCR is pasting the overtake manoeuvres on the right positions in the dataset. As the obstacles were hardcoded with a specific start position and velocity, the places in the dataset could be calculated. The final input can be found in Figure 9.

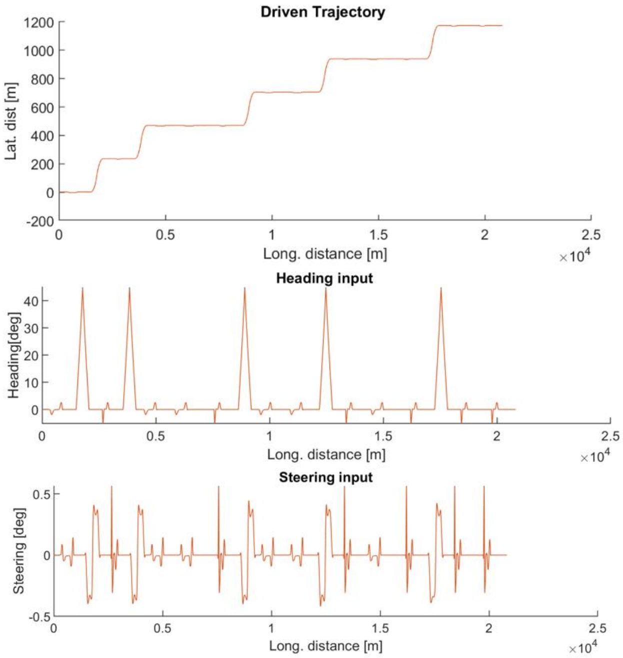


Figure 9: Final input used for controller data

TUNING FOUR-DESIGN-CHOICE CONTROLLER

The Haptic Shared Controller is tuned, so that the amount of feedback was appropriate for both providing enough feedback, but at the same time being able to fight against the system. This was tuned at 80% of the settings chosen by Scholtens.

Gain	
K_S	0.05 N
K	0.03 Nm/deg
K_{SoHF}	1.2
K_{LoHS}	0.36 Nm/rad

B

Experimental forms

DRIVING SIMULATOR RESEARCH PARTICIPATION CONSENT

Driving performance study

Introduction: This is an invitation to participate in the driving experiment for the graduation project of Karlijn Labrujere. Before participating in this study, it is important that this document, providing information about the purpose, procedures, and possible discomforts of this study, is well understood.

Purpose of the study: The purpose of this research is to investigate the effect on driving behaviour and subjective experience, for two different feedback systems. To find out, you will drive three different conditions, (1) Haptic Feedback in the form of torques on the steering wheel, (2) Haptic Feedback with reference trajectory visualized, (3) Haptic Feedback with Vehicle Limits and reference trajectory visualized. The conditions will be provided in a random order during this study. The data will be gathered and afterwards it will be analysed and anonymously published in a Master's thesis, and possibly a scientific publication.

Procedure: The total duration of this study will be approximately 1 hour and 15 minutes. Before the driving experiment starts, you will be asked to fill in a questionnaire regarding your driving habits, and your previous driving experience. Next, you will be given an explanation about the feedback systems used during the experiment. After this explanation, you will be seated in the driving simulator (a fixed-base simulator with wide-angle view). In the first phase of the experiment, you will get several short trainings to get familiar with the simulator and the different feedback systems. During this training phase, the car is held at a fixed speed, 100 km/hr, by a cruise control system. Before starting the second phase, it is important that the feedback systems are clearly understood, so please ask when something is unclear.

In the second phase, you will drive 3 trials of 12 minutes each, where you will experience the feedback systems in random order. Again, the speed is fixed at 100 km/hr. Your task in this experiment is to drive as you normally would with the given feedback systems. During the experiment you have to drive on the right lane, unless you need to change lane to take-over another vehicle. After finishing this manoeuvre you should turn back to the right lane. After each trial you will have a short break, outside the simulator, in which you are asked to answer a questionnaire to assess your subjective experience and acceptance of the driven feedback system or combination of feedback systems.

Risks, discomforts & benefits: During this experiment there is a risk of simulator sickness, with symptoms similar to motion sickness. The trials are relatively short, around 12 minutes each, with a small break after each trial. However, if you feel uncomfortable, you have the right to stop participating at any time without any negative consequences. The benefits for you are no other than a minor treat as thanking you for the participation and a hands on experience in a driving simulator.

Confidentiality: All data collected in this study will be kept confidential and will be used for research purpose only. Throughout the whole study, you will be identified by a participant number. If you feel like withdrawing your collected data, you can contact Karlijn Labrujere, by giving your participant number.

Right to refuse or withdraw: Your participation is strictly voluntary and you may refuse or stop participating at any time without any negative consequences.

Contact details: For more information or concerns about this experiment, please feel free to contact:

Karlijn Labrujere
Faculty of Mechanical Engineering, TU Delft – Mekelweg 2, 2628 CD Delft
Phone: +31 6 83 79 56 96 E-mail: k.m.labrujere@student.tudelft.nl

I acknowledge that I completely understand this consent and I agree to participate in this study.

Signature of participant: Date:

DRIVING EXPERIENCE QUESTIONNAIRE

Driving performance study

1. *Subject number:*
   ____
2. *First Name + Surname*
   ____
3. *E-mail address*
   ____
4. *Gender*
   a. Female
   b. Male
   c. Prefer not to say
5. *What is your primary mode of transportation?*
   a. Private vehicle
   b. Public transportation
   c. Motorcycle
   d. Walking/cycling
   e. Prefer not to say:
   f. Different:_______________
6. *At what age did you obtain your first (car) driver's license?*
   ____
7. *About how many kilometres did you drive in the last 12 months?*
   a. 0
   b. 0 – 1,000
   c. 1,001 – 5,000
   d. 5,001 – 10,000
   e. 10,001 – 15,000
   f. 20,001 – 25,000
   g. 25,000 – 35,000
   h. 35,000 – 50,000
   i. 50,001 – 100,000
   j. More than 100,000
8. *What is your general opinion about automated driving functions?*
   E.g. Cruise Control (CC), Adaptive Cruise Control (ACC), Lane Keeping Assist, Traffic jam assist
   a. Absolute positive
   b. Positive
   c. Neutral
   d. Negative
   e. Absolute negative
9. *Do you have experience driving with automated driving functions?*
   a. Yes
   b. No
   c. Prefer not to say
10. *Do you understand the intent/working principle/implementation of automated driving functions?*
    a. Fully
    b. Partly
    c. Not at all
    d. Prefer not to say
11. *Do you trust automated driving functions?*
    a. Fully
    b. Partly
    c. Not at all
    d. Prefer not to say
12. *Describe why you trust or do not trust an automated driving function:*
    ____

VAN DER LAAN QUESTIONNAIRE AND SUBJECTIVE EXPERIENCE

Driving performance study

Van der Laan Questionnaire

My judgements of the assistance system for this overtake type are…

Useful Useless
|________|________|________|________|

Pleasant Unpleasant
|________|________|________|________|

Bad Good
|________|________|________|________|

Nice Annoying
|________|________|________|________|

Effective Superfluous
|________|________|________|________|

Irritating Likeable
|________|________|________|________|

Assisting Worthless
|________|________|________|________|

Undesirable Desirable
|________|________|________|________|

Raising alertness Sleep inducing
|________|________|________|________|

Extra questionnaire

Please indicate if you would have liked the assistance torque to be more or less:

Less Neutral More
|___|___|___|___|___| |___|___|___|___|___|

Please indicate if you would have liked to start the overtake earlier or later:

Earlier Neutral Later
|___|___|___|___|___| |___|___|___|___|___|

I can trust the assistance system:

Not at all Neutral Fully
|___|___|___|___|___| |___|___|___|___|___|

I am suspicious of the system's intent or actions:

Not at all Neutral Fully
|___|___|___|___|___| |___|___|___|___|___|

END QUESTIONNAIRE

Driving performance study

1. *Subject number:*

   ____

2. *I prefer driving with:*
   a. Haptic Shared Control
   b. Haptic Shared Control & Visualized Trajectory
   c. Haptic Shared Control & Visualized Trajectory & Visualized Vehicle Information

3. *Why?*

   ____

4. *I understood the intent of the controller best in:*
   a. Haptic Shared Control
   b. Haptic Shared Control & Visualized Trajectory
   c. Haptic Shared Control & Visualized Trajectory & Visualized Vehicle Information

5. *Why?*

   ____

6. *I trust the system most driving with:*
   a. Haptic Shared Control
   b. Haptic Shared Control & Visualized Trajectory
   c. Haptic Shared Control & Visualized Trajectory & Visualized Vehicle Information

7. *Why?*

   ____

8. *Additional comments?*

   ____

C

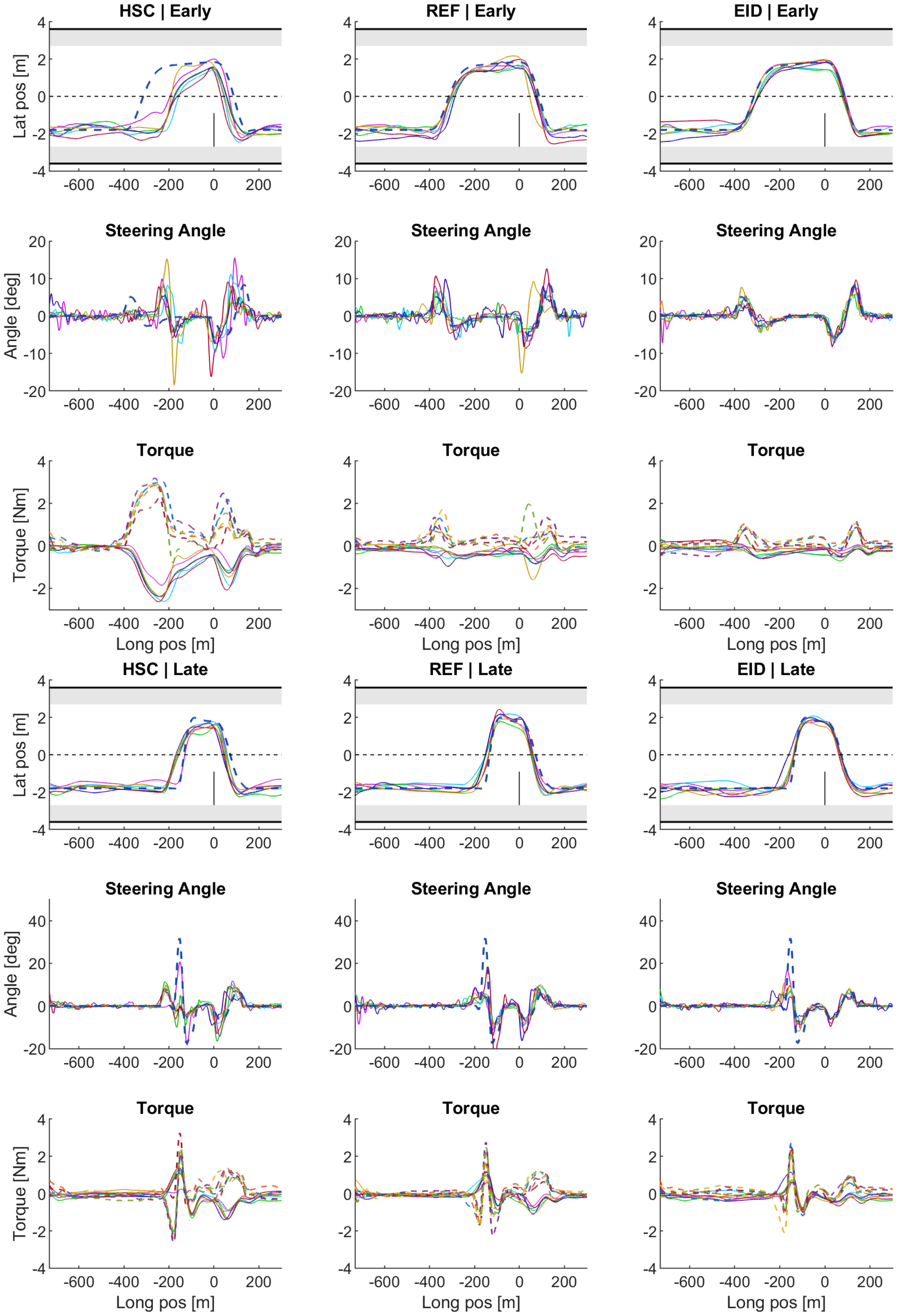
Pilot Study

In order to validate designed experiment, a pilot study has been performed. The goal of this pilot study was to obtain a first insight about the effect on driving behavior with the different feedback conditions, check whether all data was logged correctly, and gather knowledge about participant's opinion.

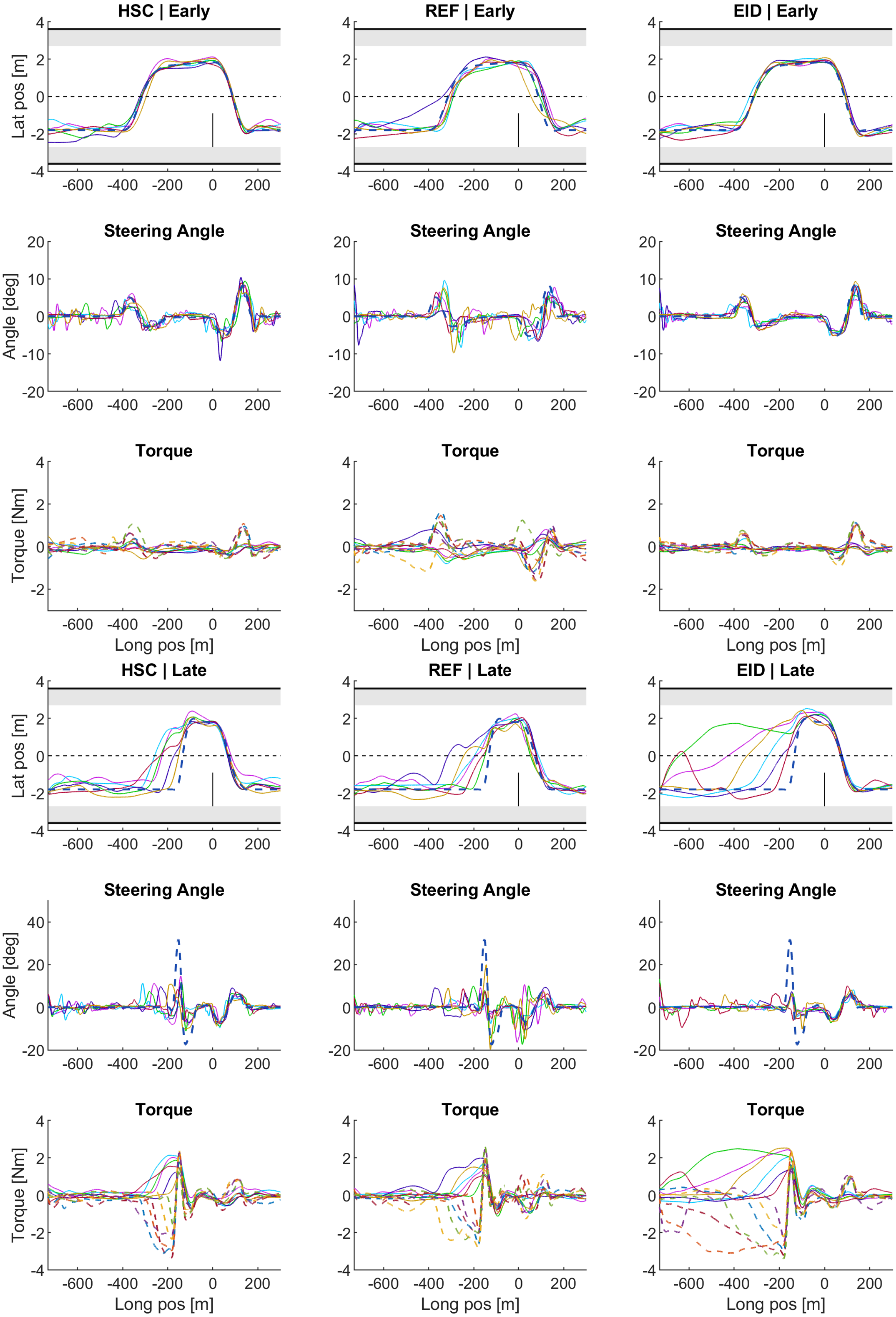
From this pilot study, it could be concluded that the driving simulator logged all required data correctly. However, one small mistake was made in road order for participant 3, where order varied from road 1, road 3, road 1. This led to difficulties writing a code applicable for all participants. Therefore, check .xml files before starting experiment.

From analysing raw data driven by three participants, it can be seen that participant 1 shows a non-compatible behavior when driving without visuals, mainly visible for early initiated overtake, where it shows a compatible behavior when driving with visuals. This can either be seen by position data, as by steering and torque data. Participant 2, however, shows compatible behavior while driving with all feedback conditions, where a the distinction can be made between early and late. For the early overtake the participant is prone to follow, where for the late overtake the participant is non-compatible. Especially, for EID-inspired visual feedback, the participant shows extreme fighting behavior. At last, participant 3 shows compatible behavior for all driven feedback conditions where, similar to participant 2, it is compatible to HSC intended trajectory for early overtake. However, for late overtake however, it is not-compatible, where for driving without visuals it is most compatible with HSC intended trajectory. Here, it can be seen that all three participant showed different driving behavior, where providing visual information did affect driving behavior. Therefore, the main effect should be further analysed with an increased sample size.

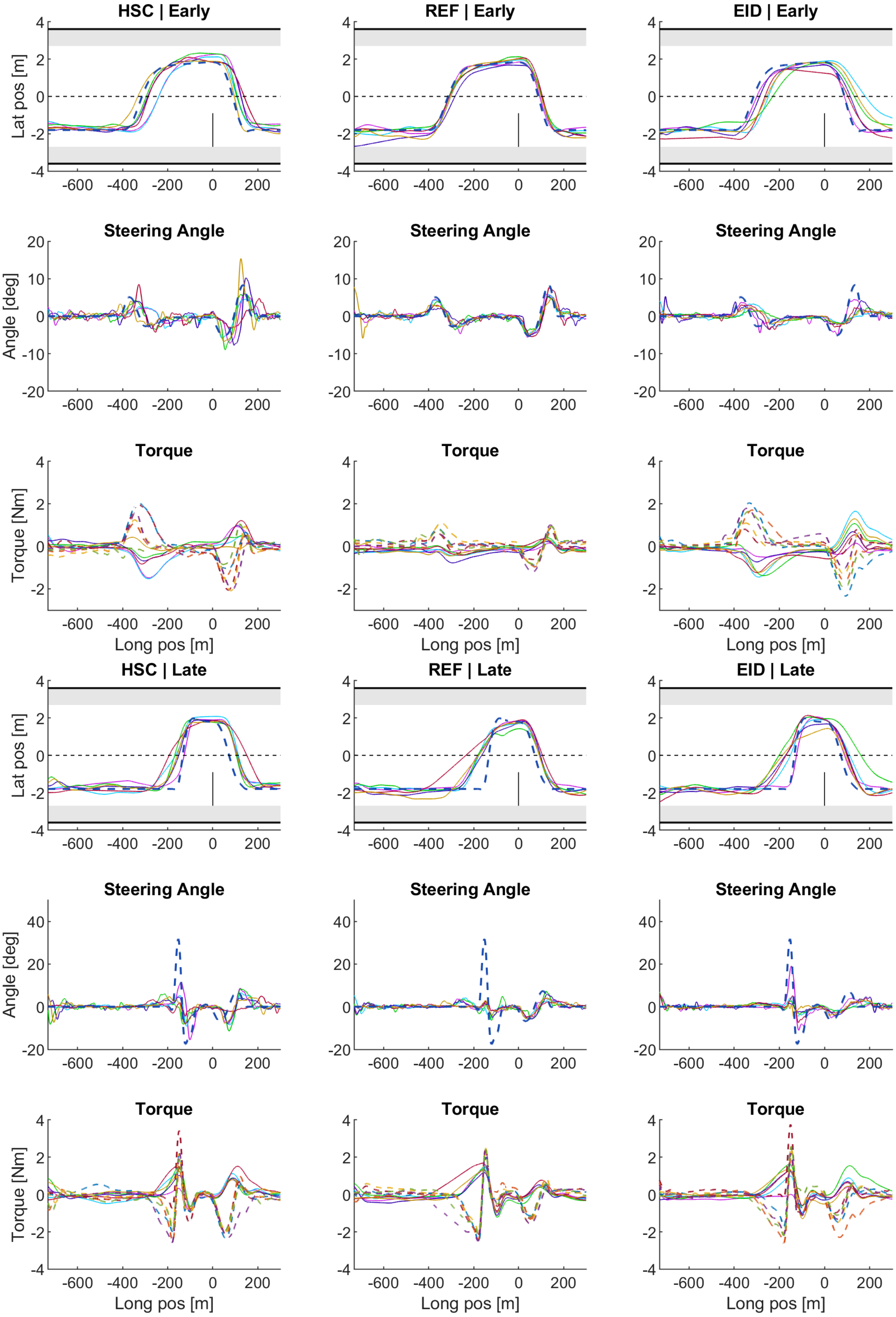
Pilot Study | Participant 1



Pilot Study | Participant 2



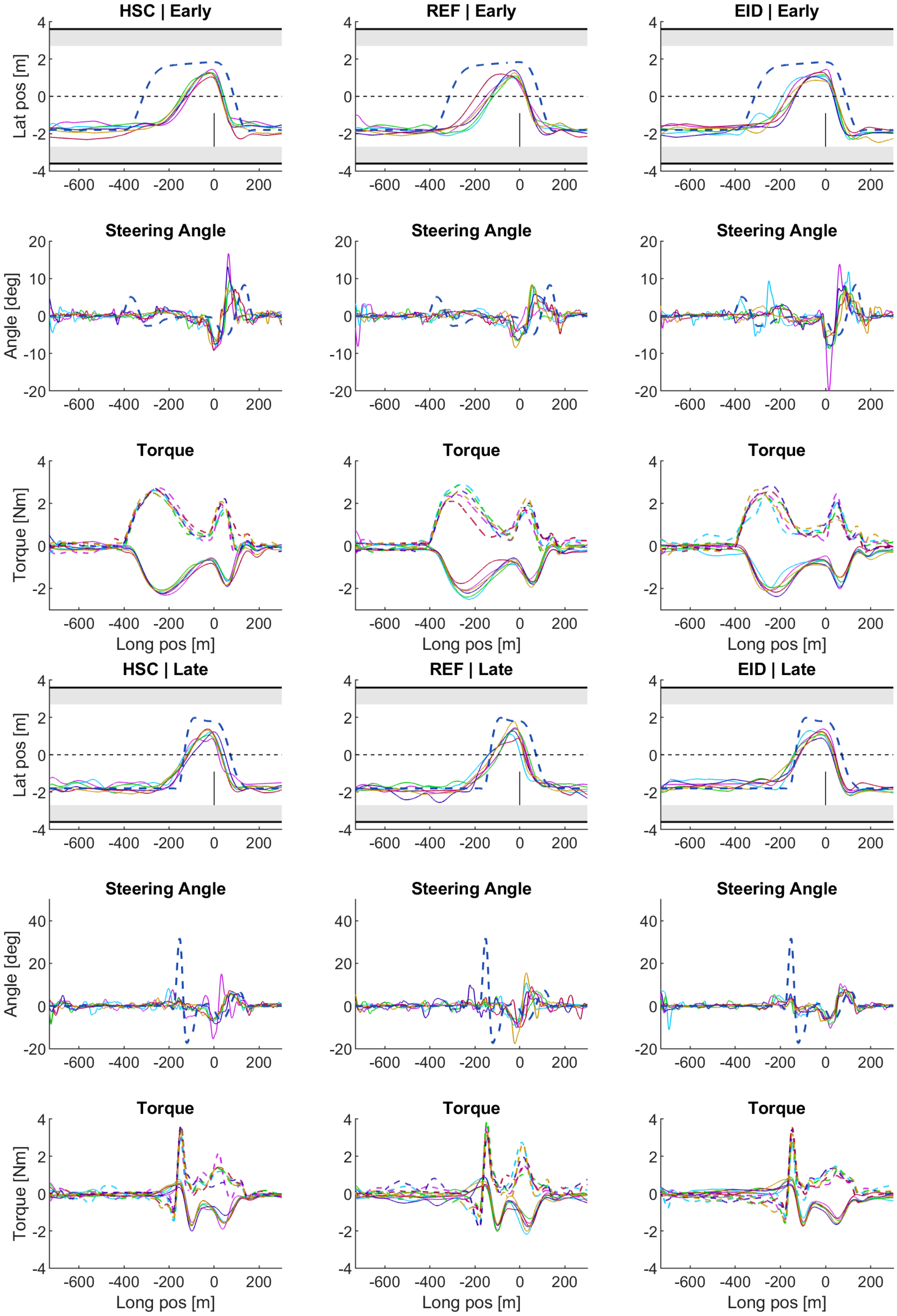
Pilot Study | Participant 3



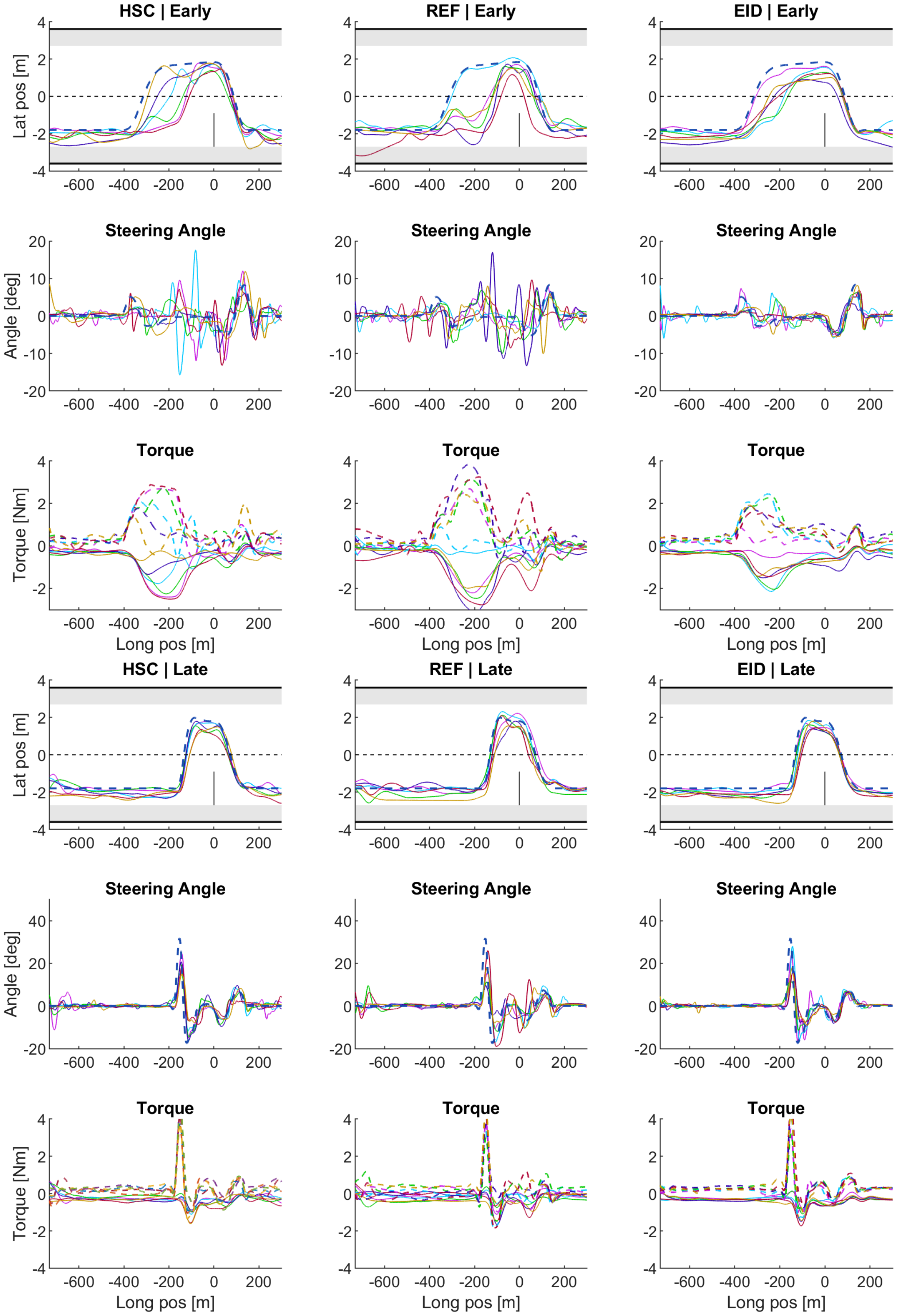
D

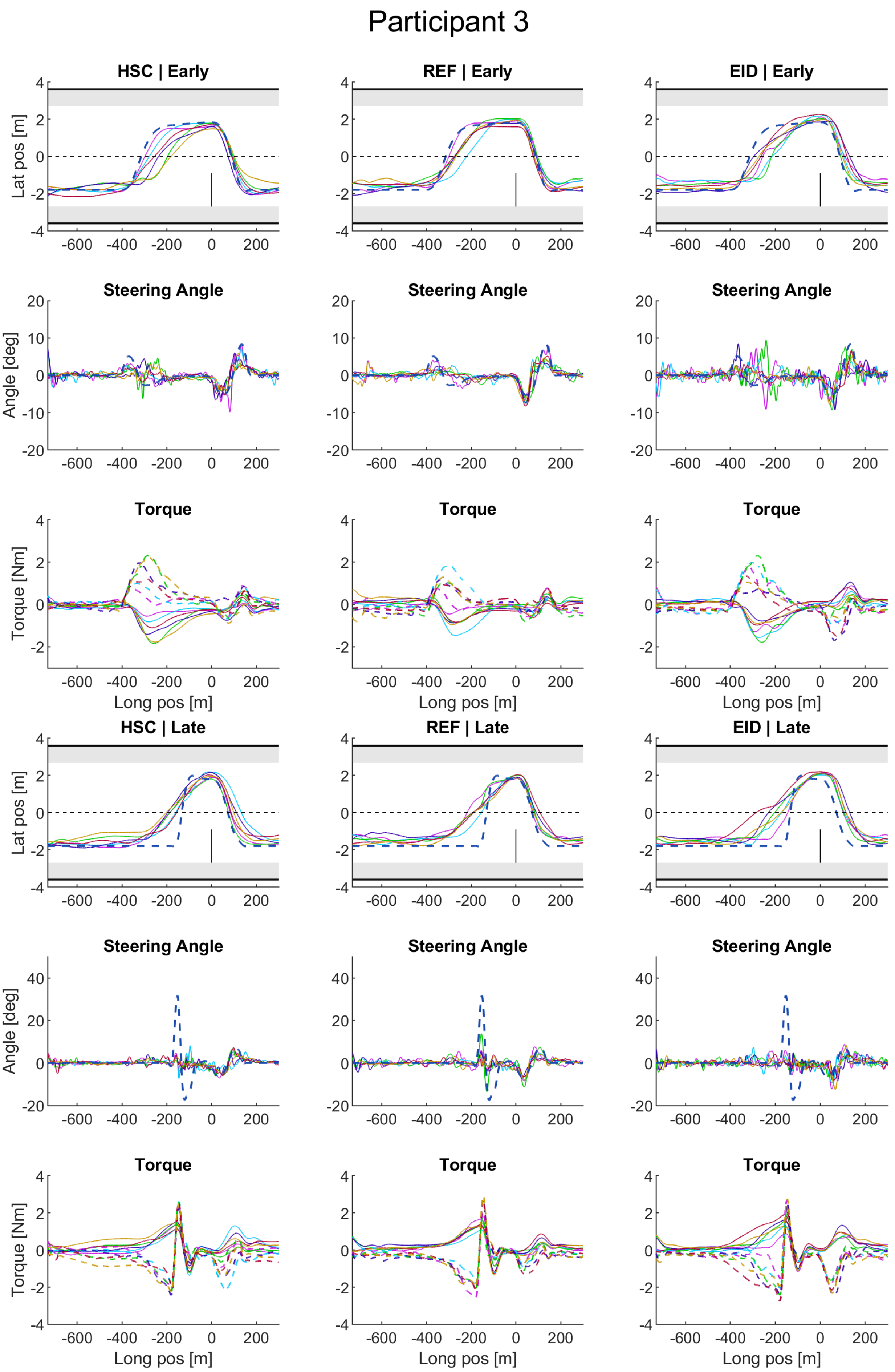
Raw Data

Participant 1

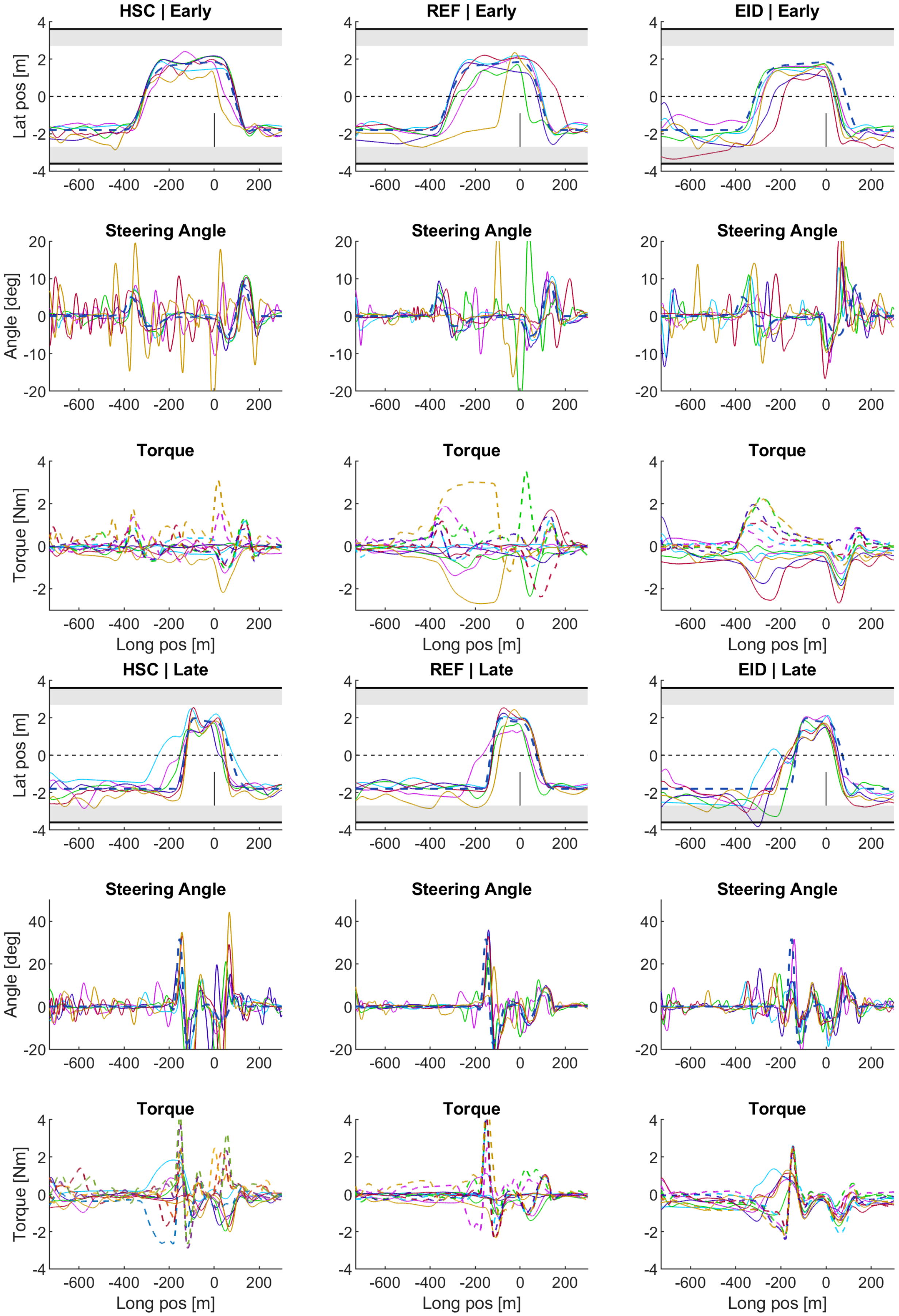


Participant 2

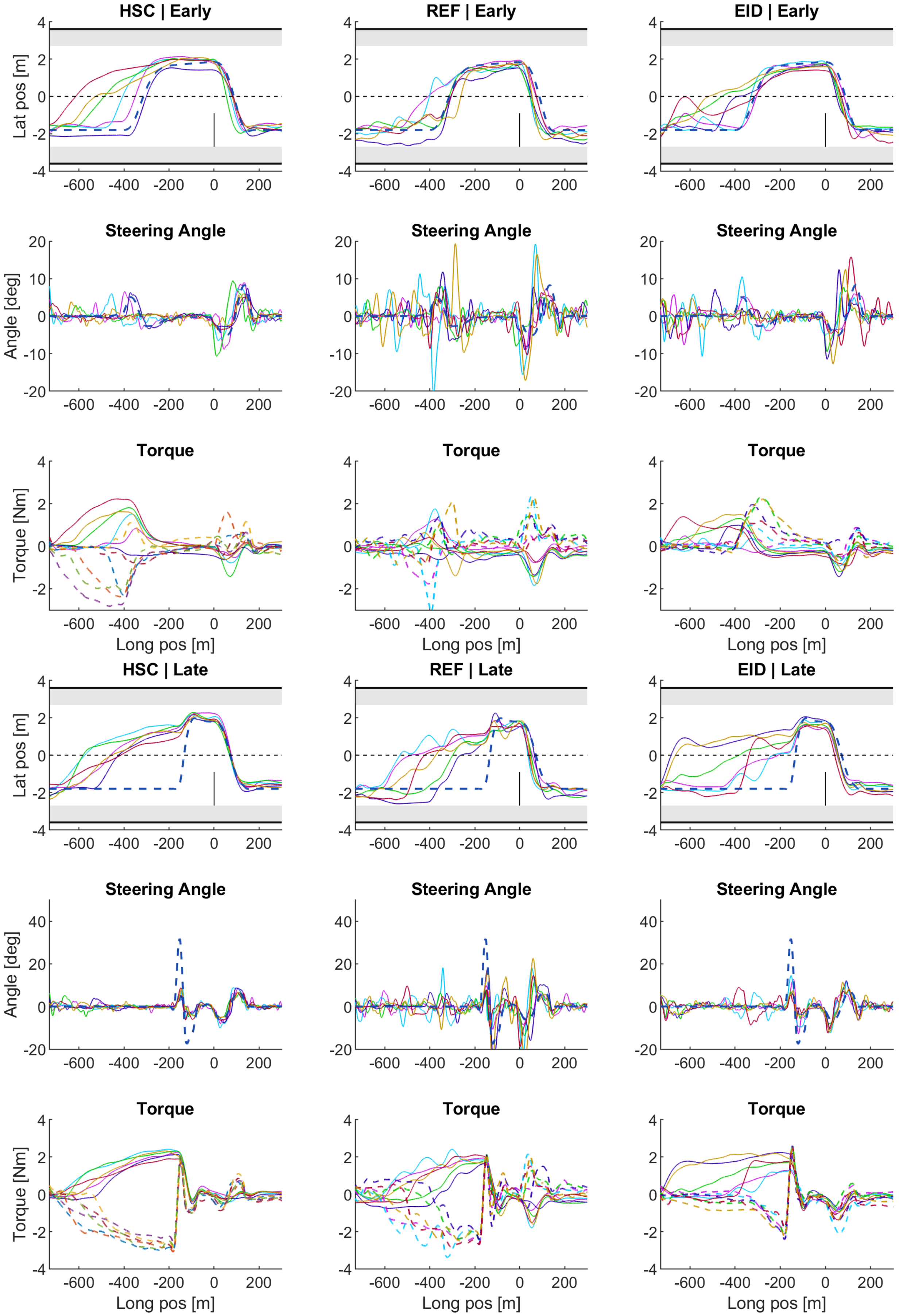



Participant 3
HSC | Early
REF | Early
EID | Early
Lat pos [m]
4
2
0
-2
-4
-600
-400
-200
0
200
Steering Angle
Angle [deg]
20
10
0
-10
-20
Torque
Torque [Nm]
Long pos [m]
HSC | Late
REF | Late
EID | Late
Steering Angle
Angle [deg]
40
20
0
-20
Torque
Torque [Nm]
Long pos [m]

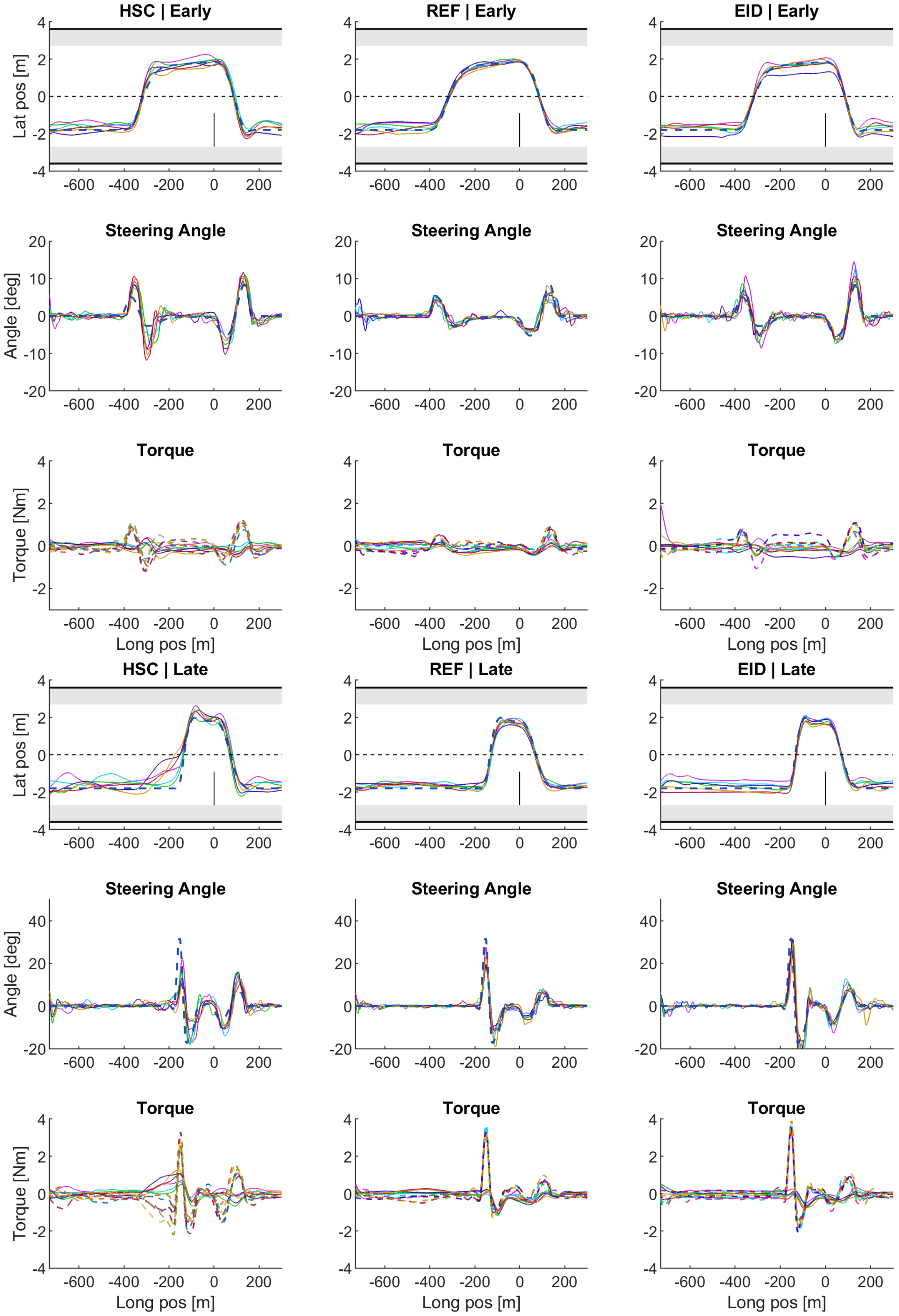
Participant 4



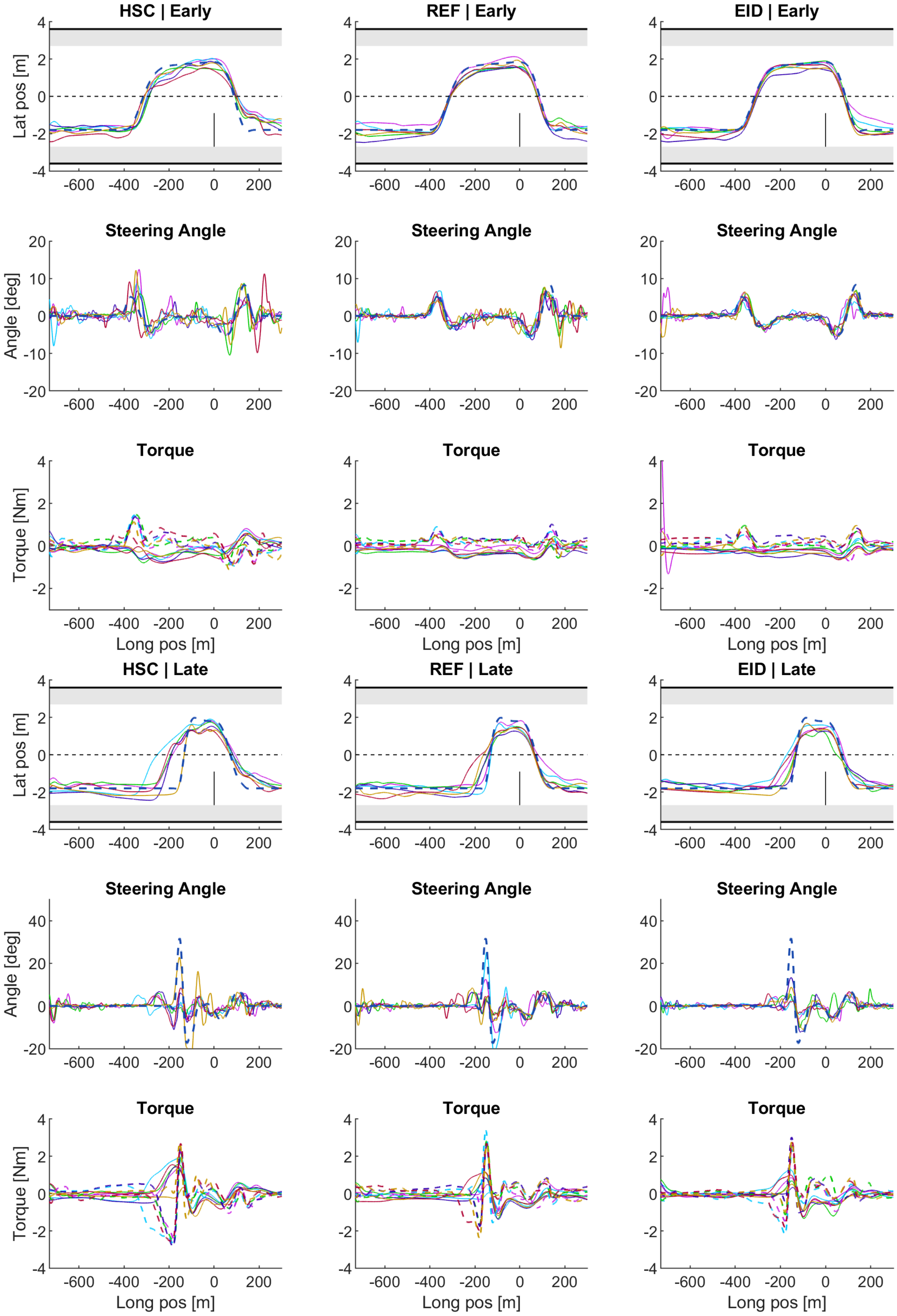
Participant 5



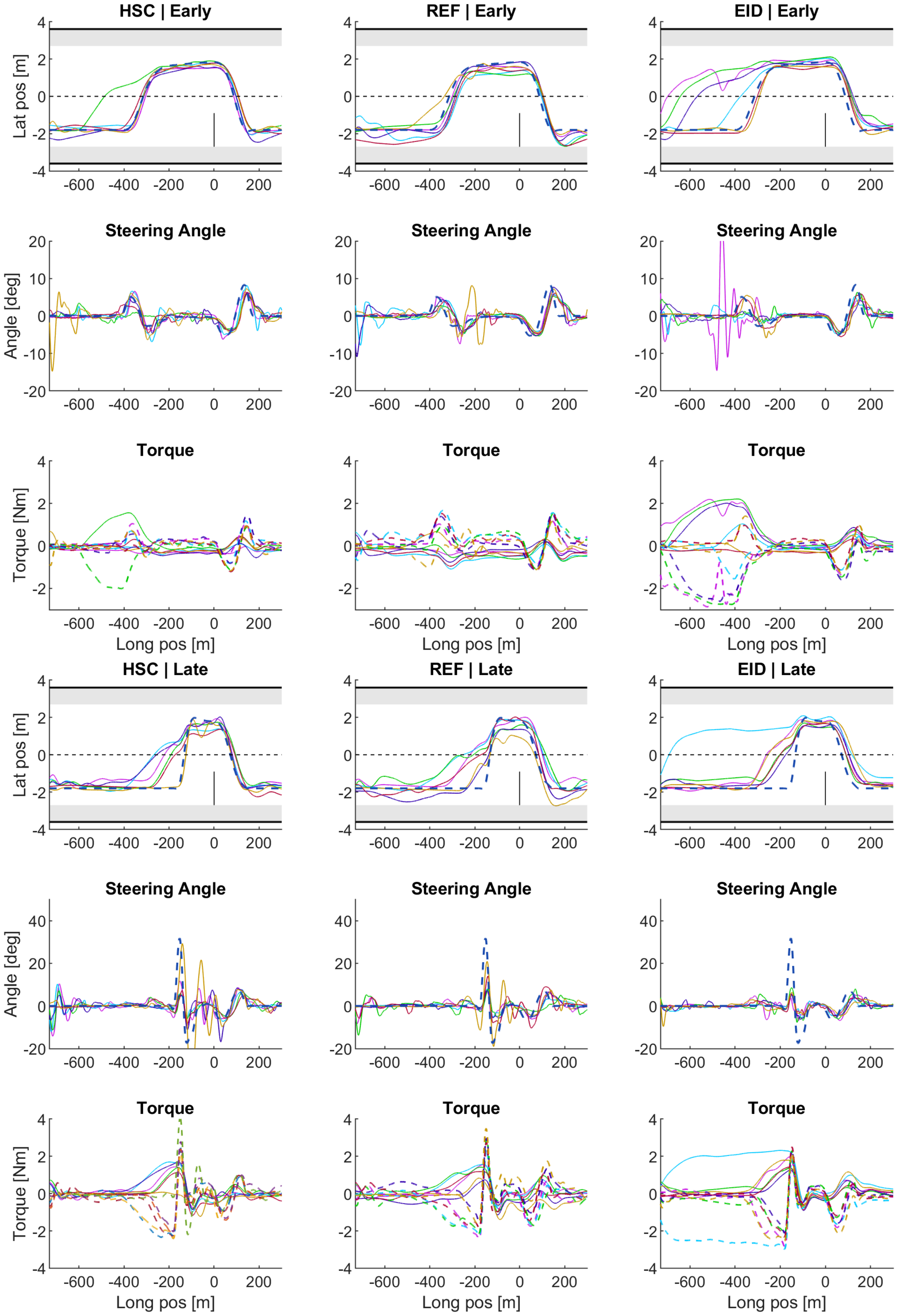
Participant 6



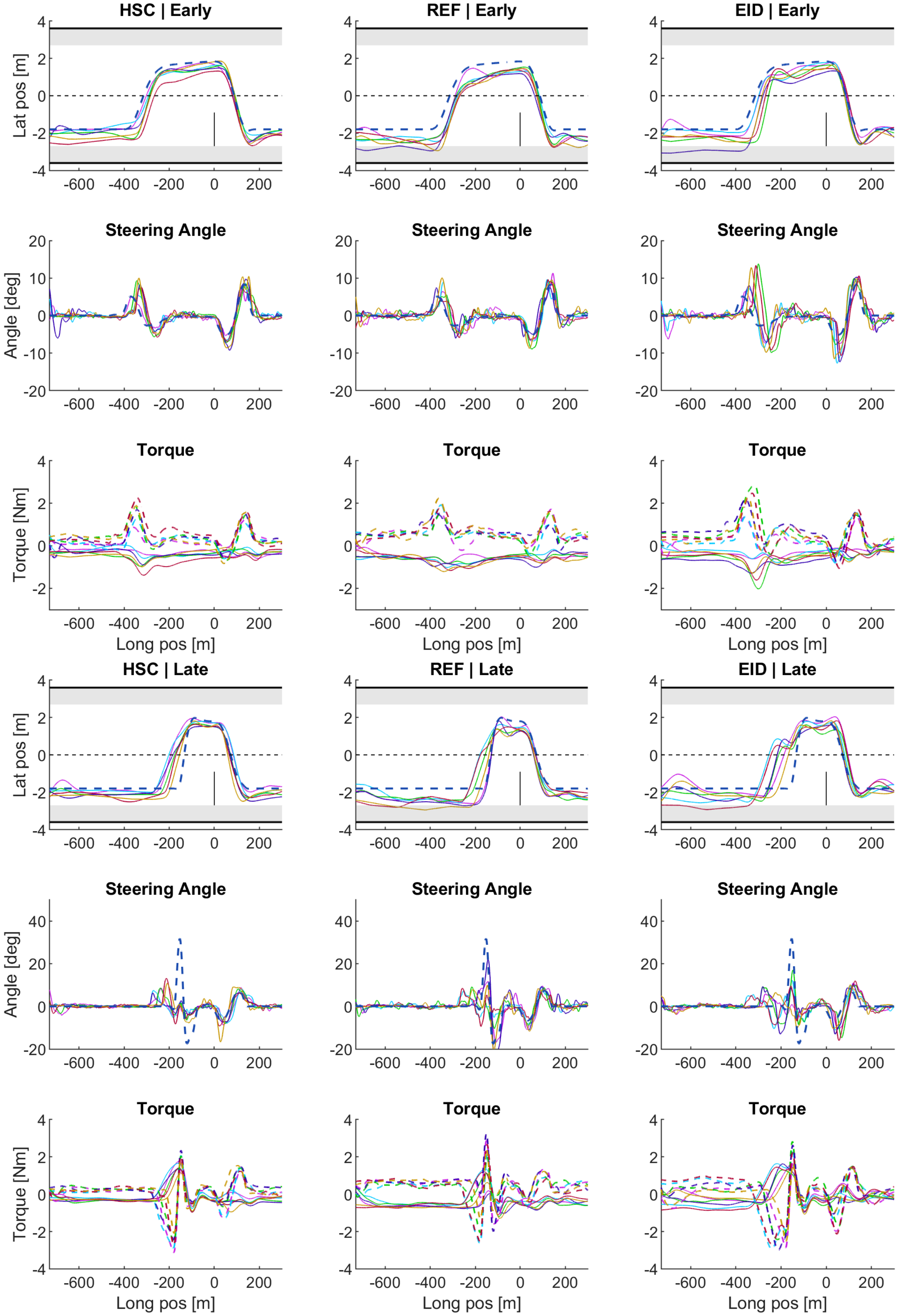
Participant 7



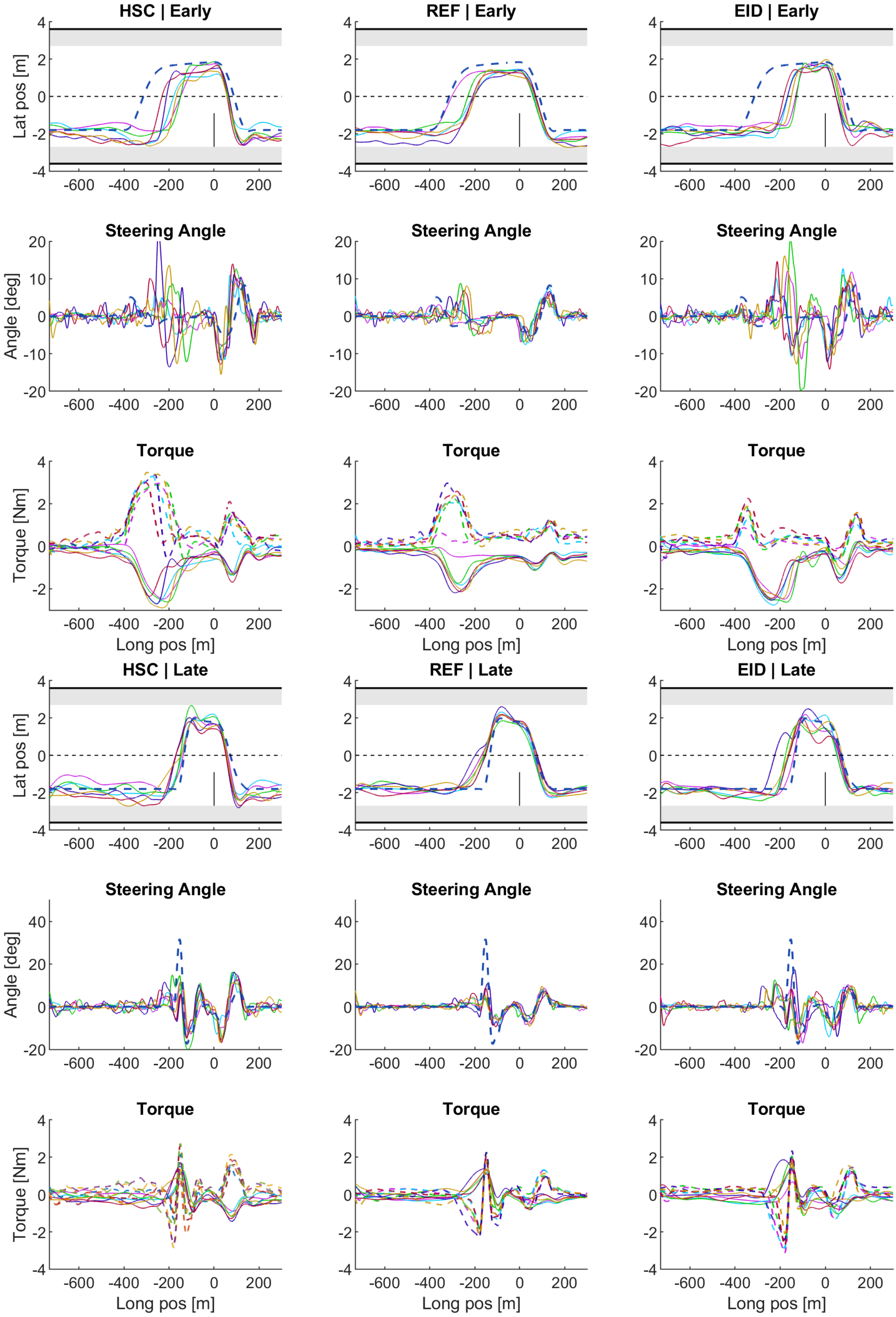
Participant 8



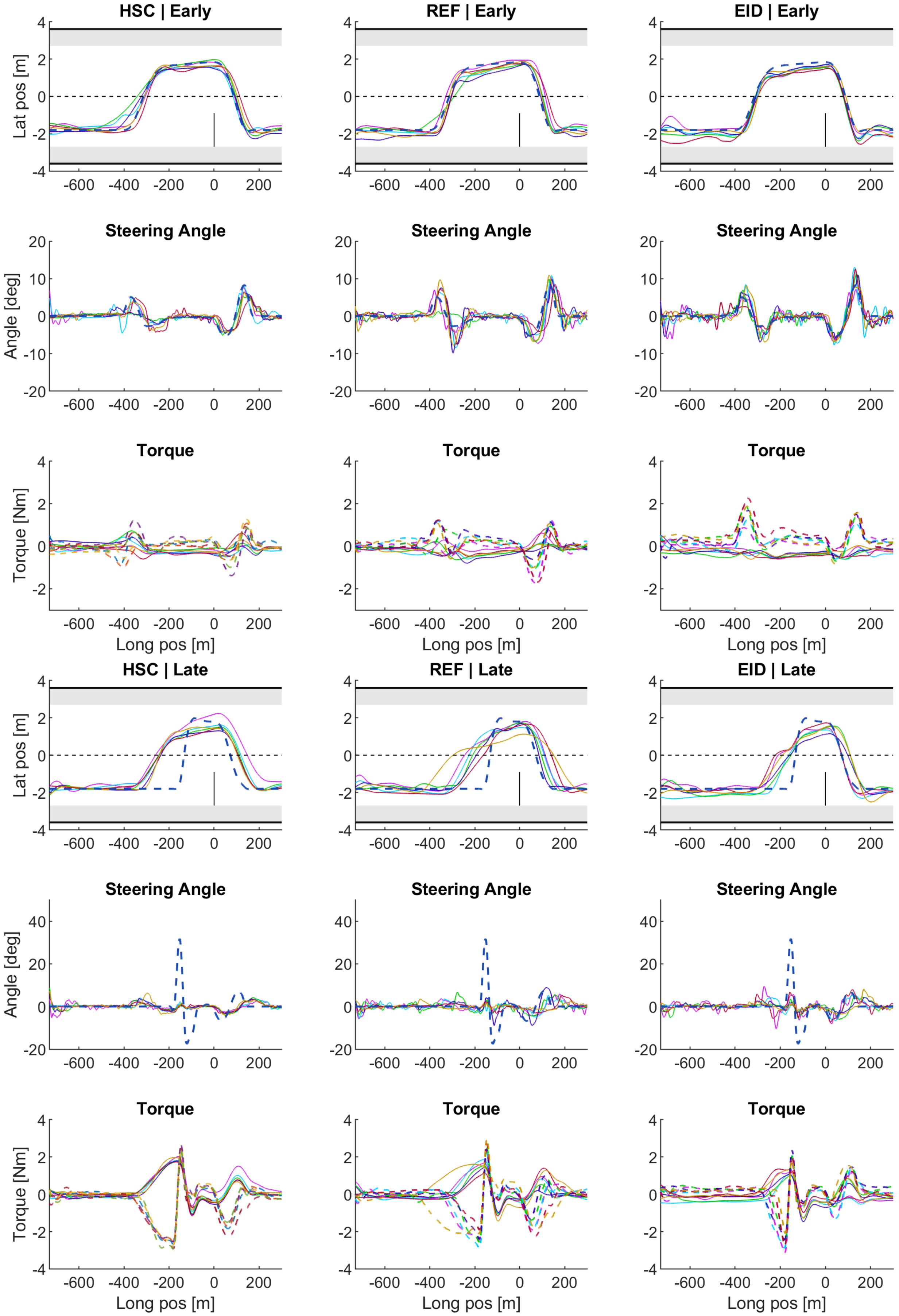
Participant 9



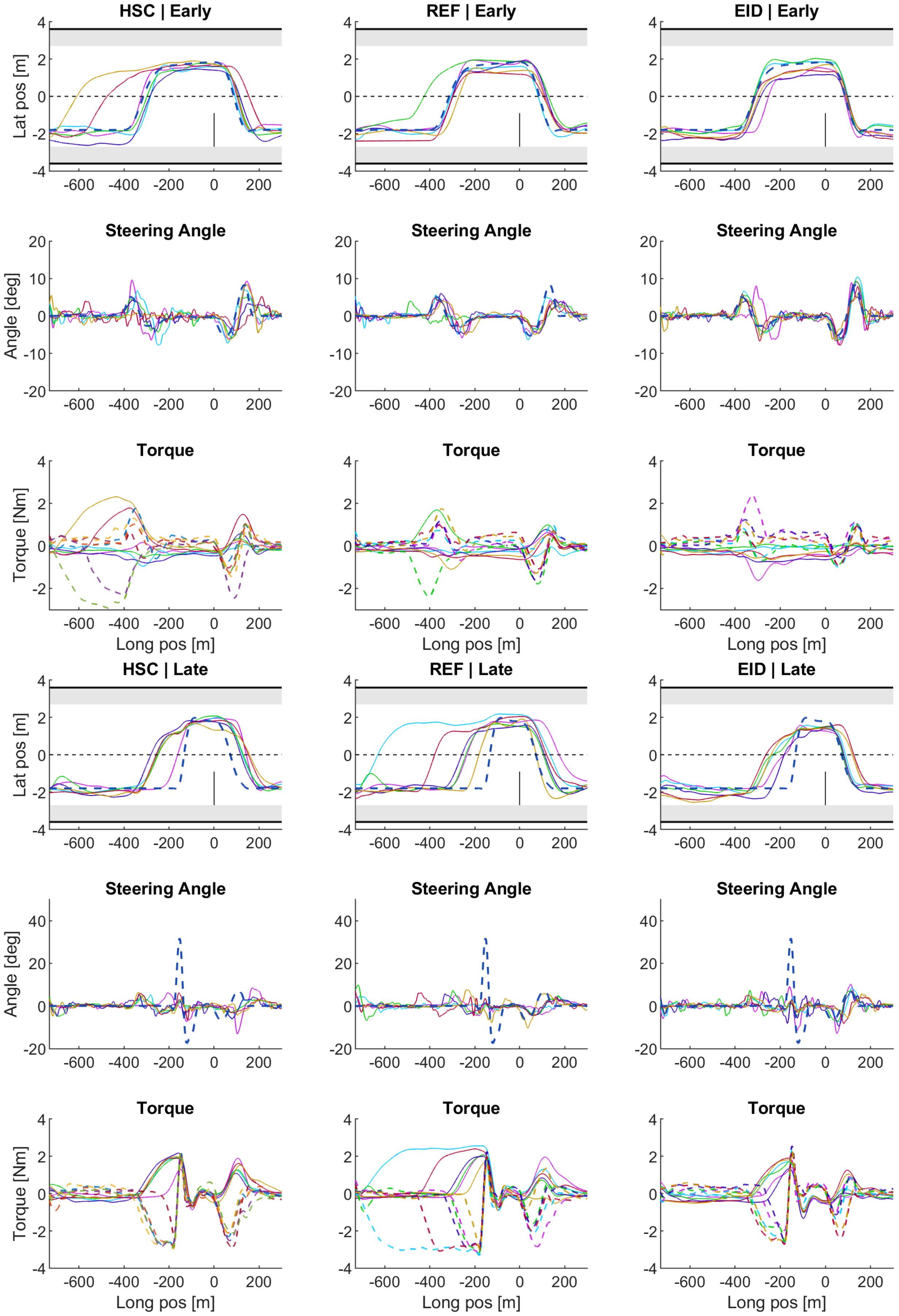
Participant 10



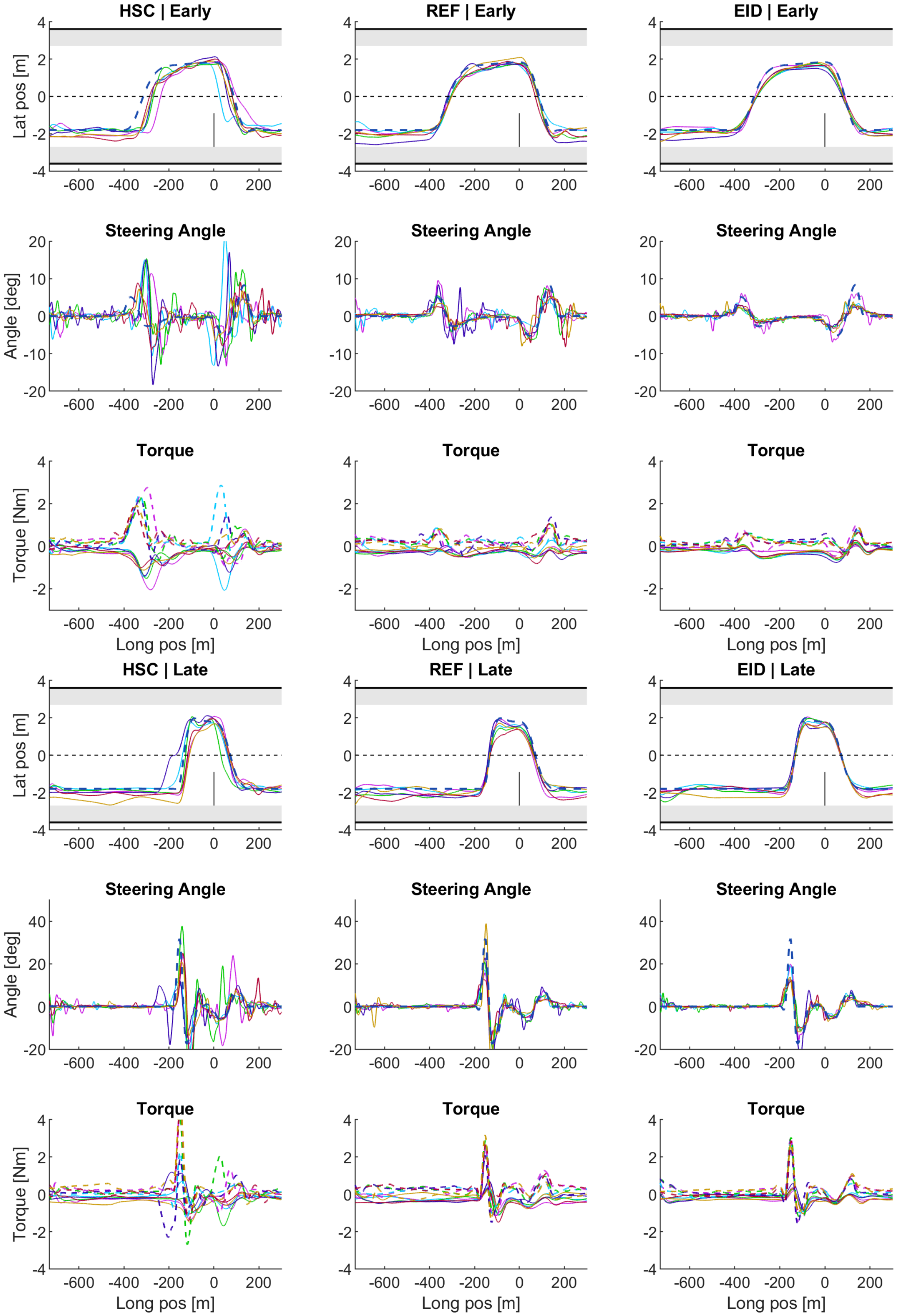
Participant 11



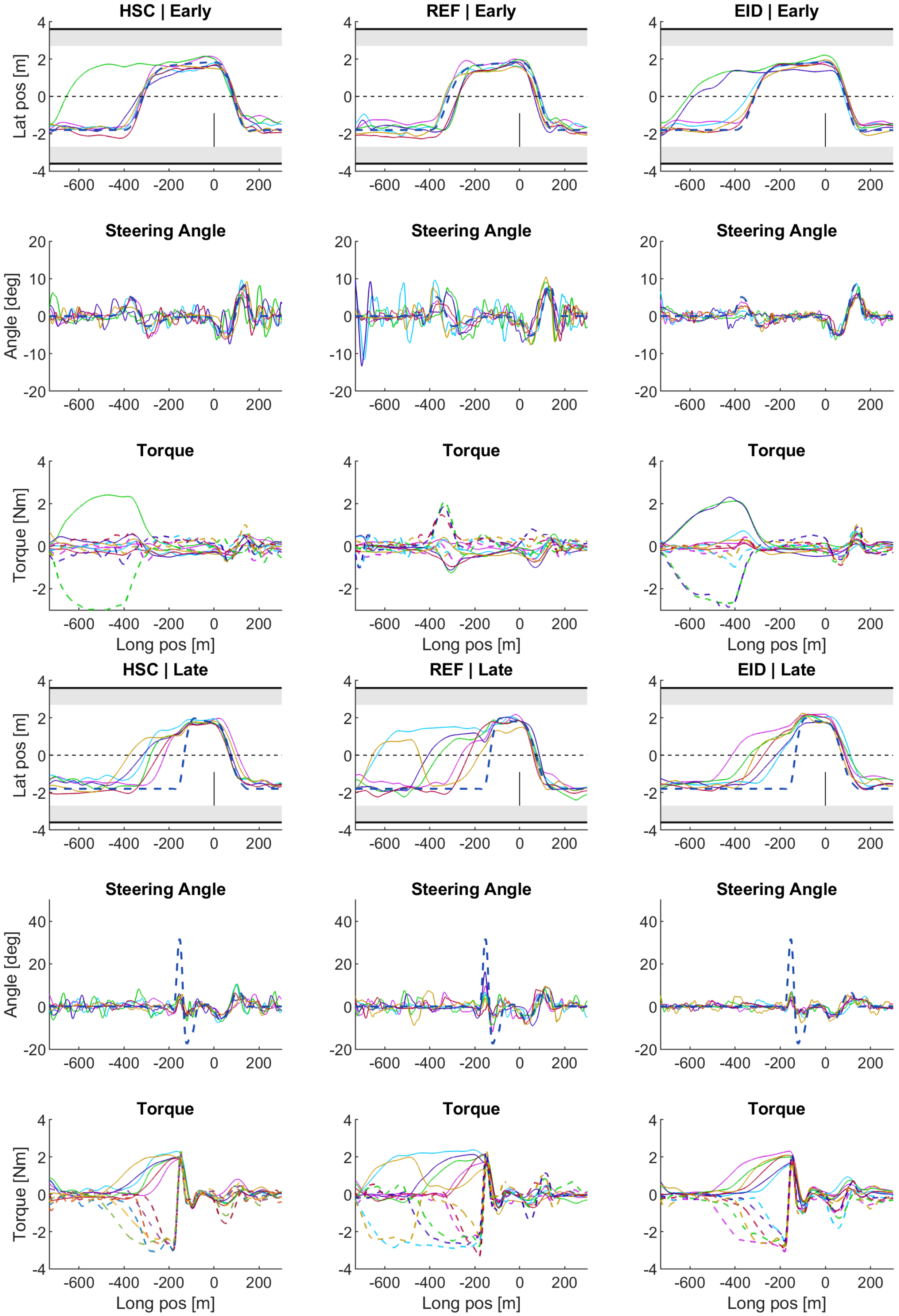
Participant 12



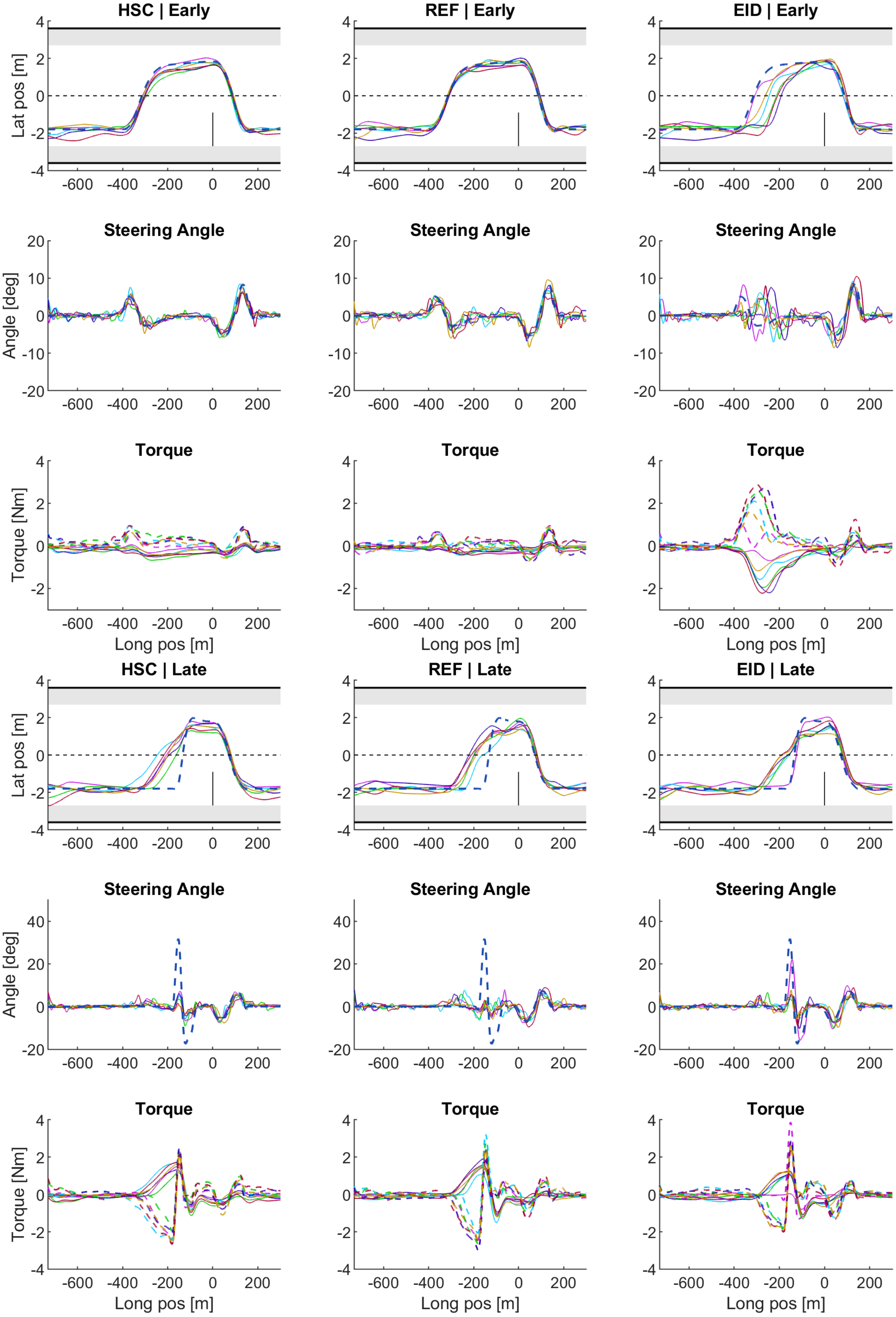
Participant 13



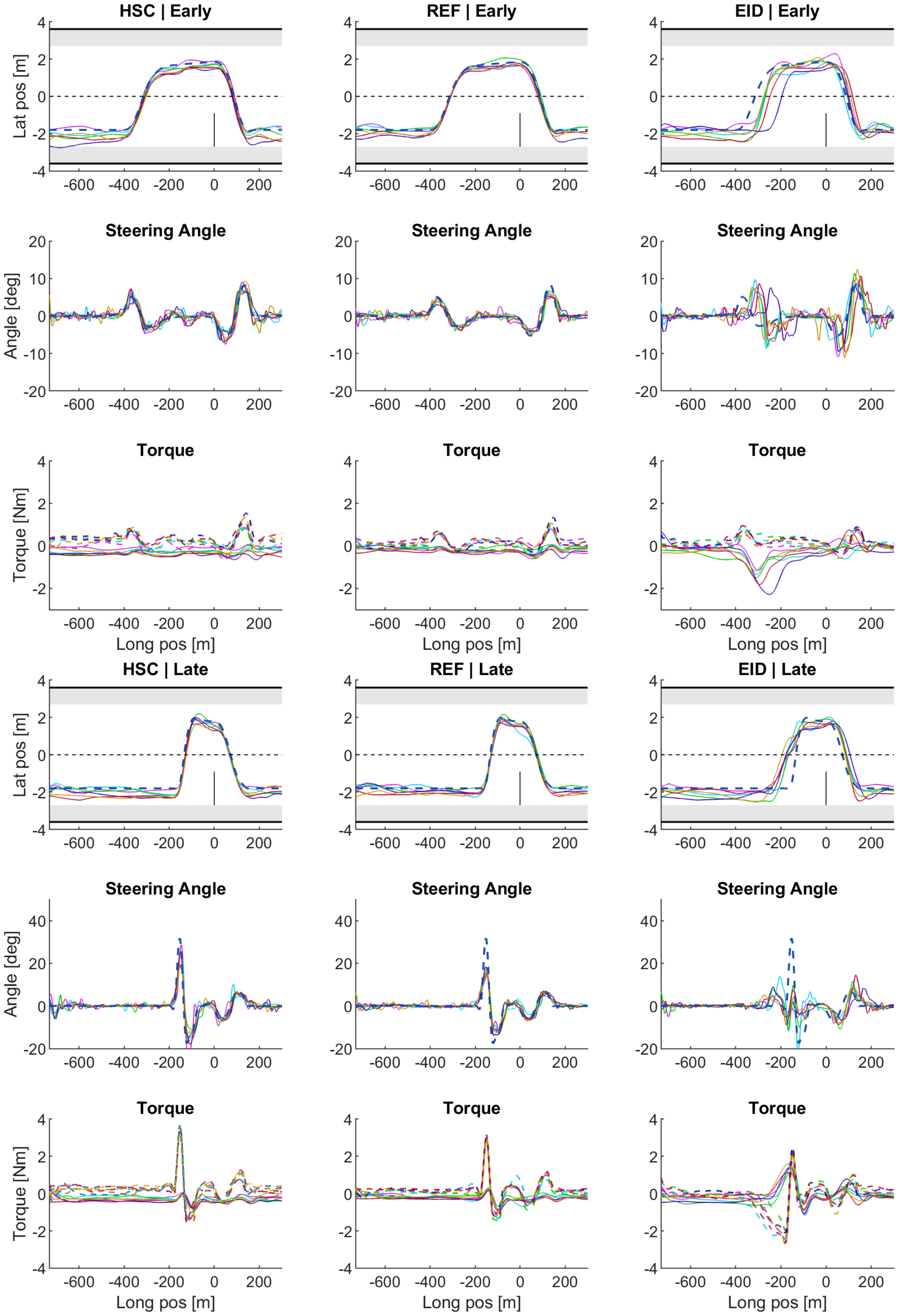
Participant 14



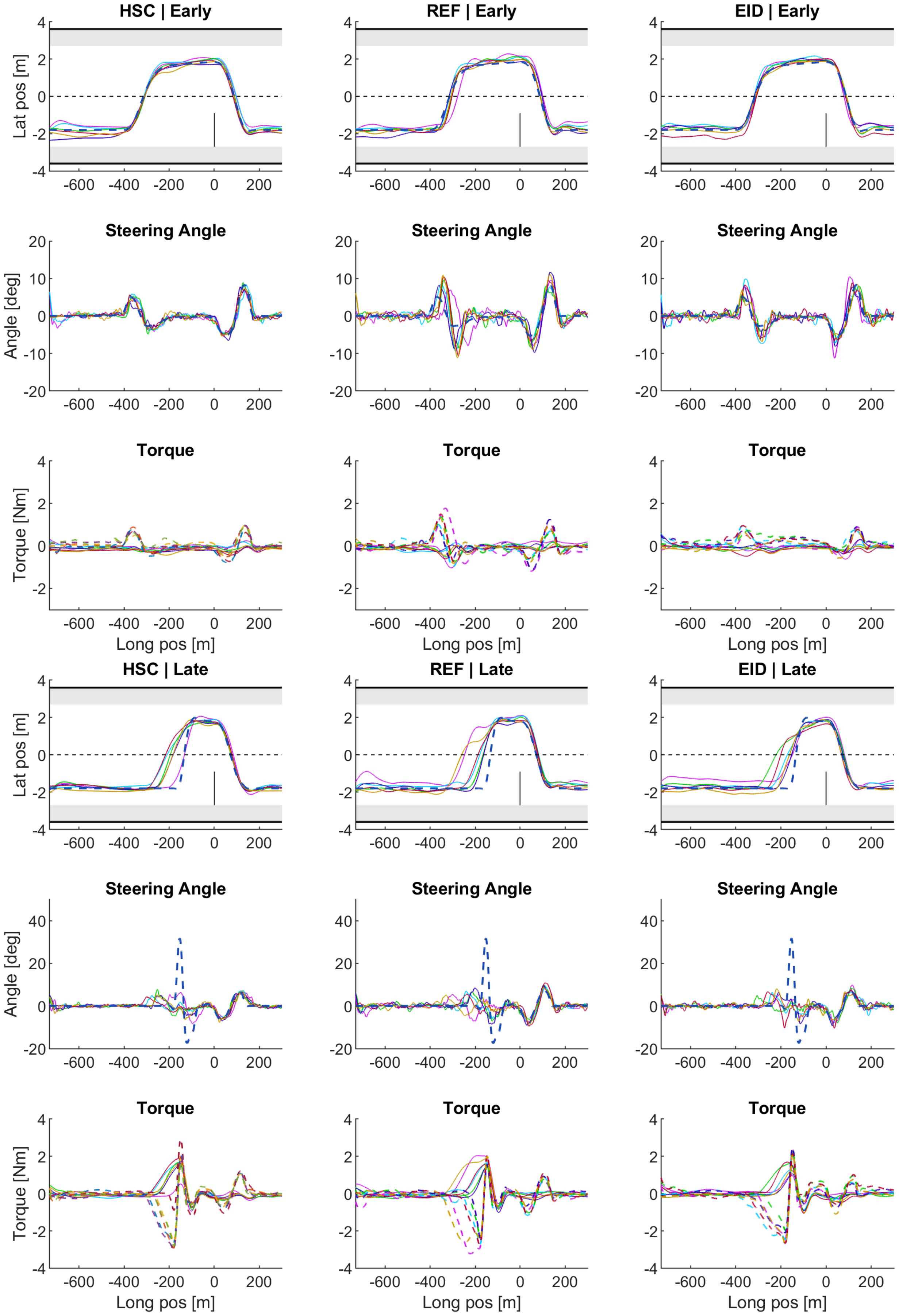
Participant 15



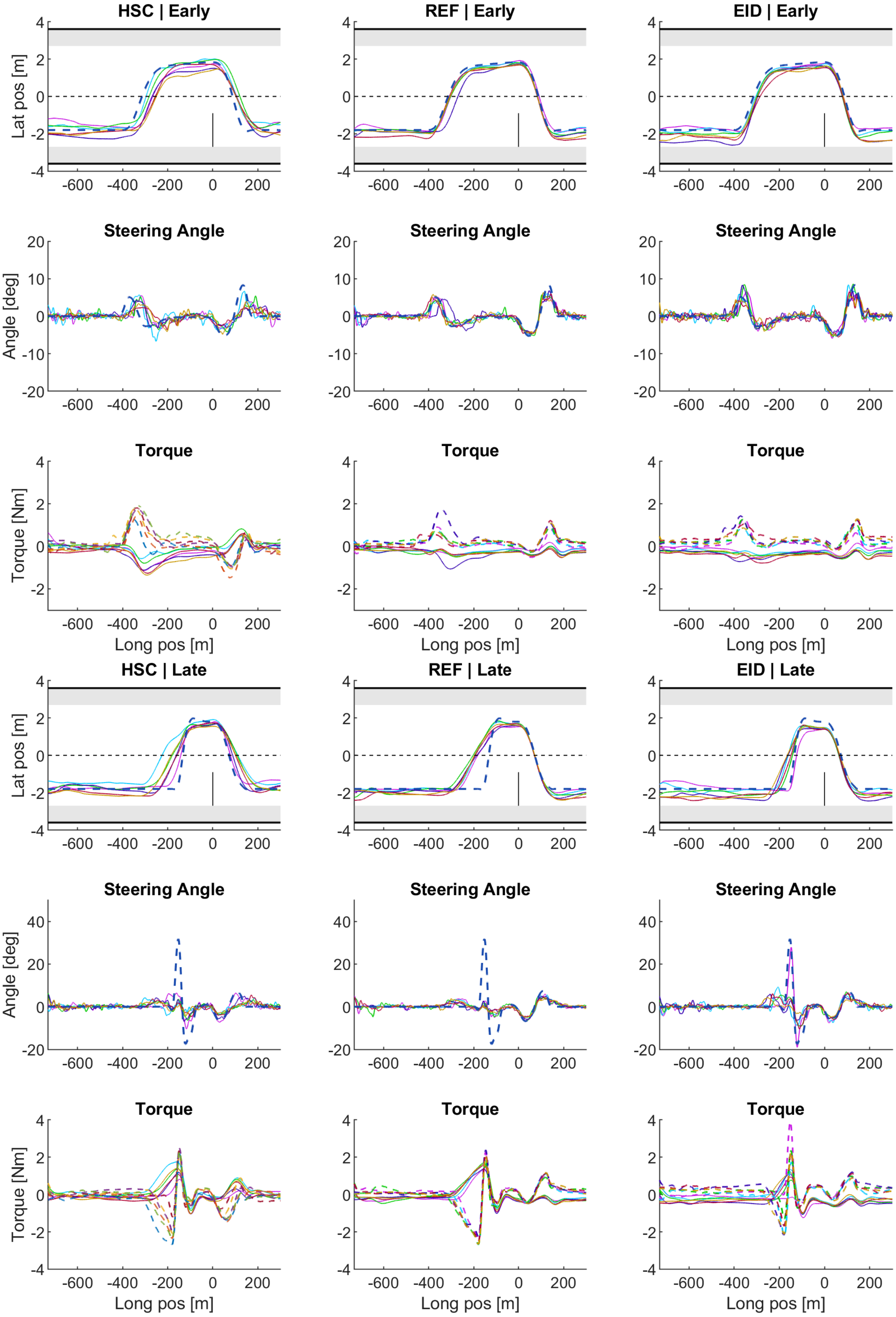
Participant 16



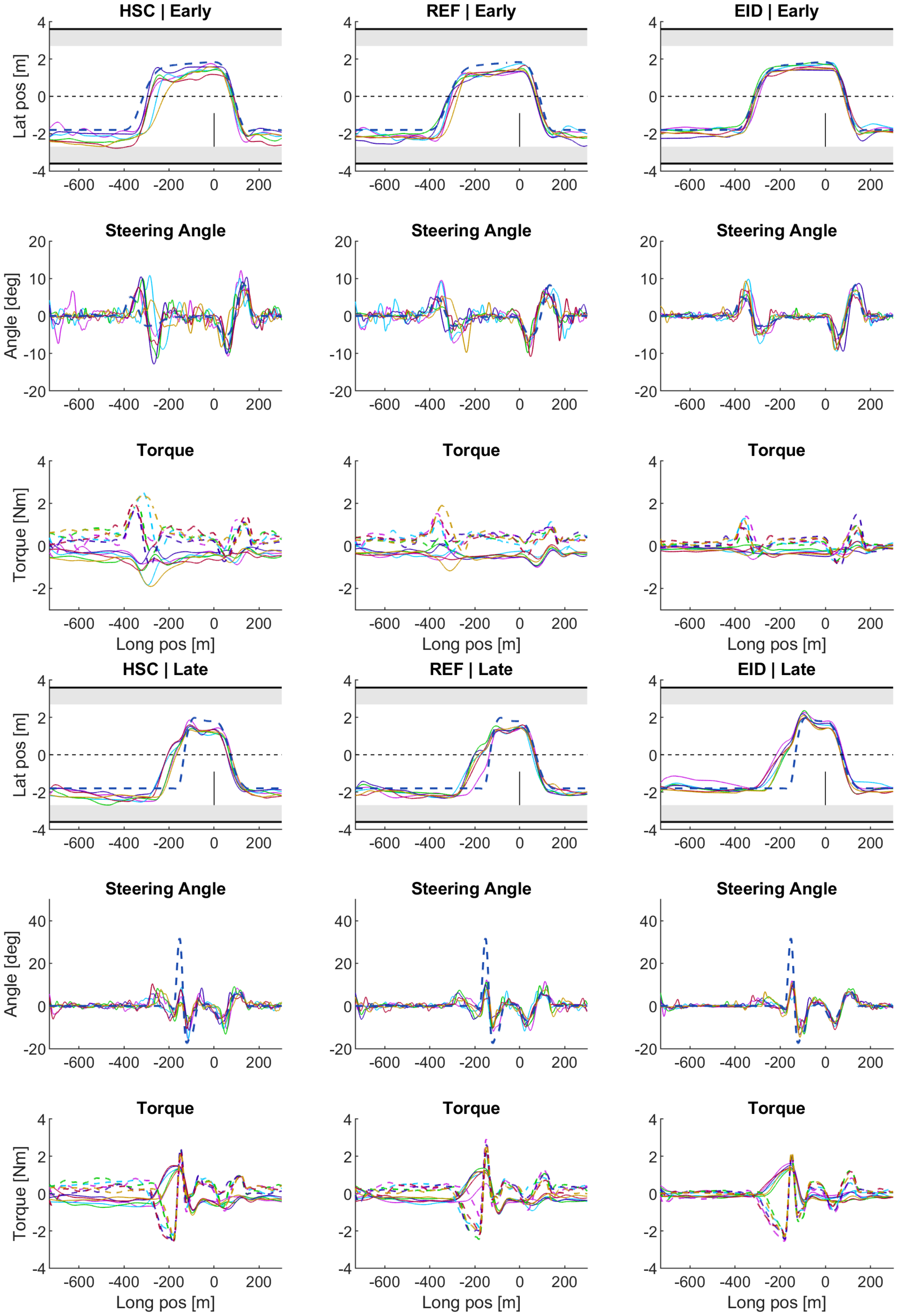
Participant 17



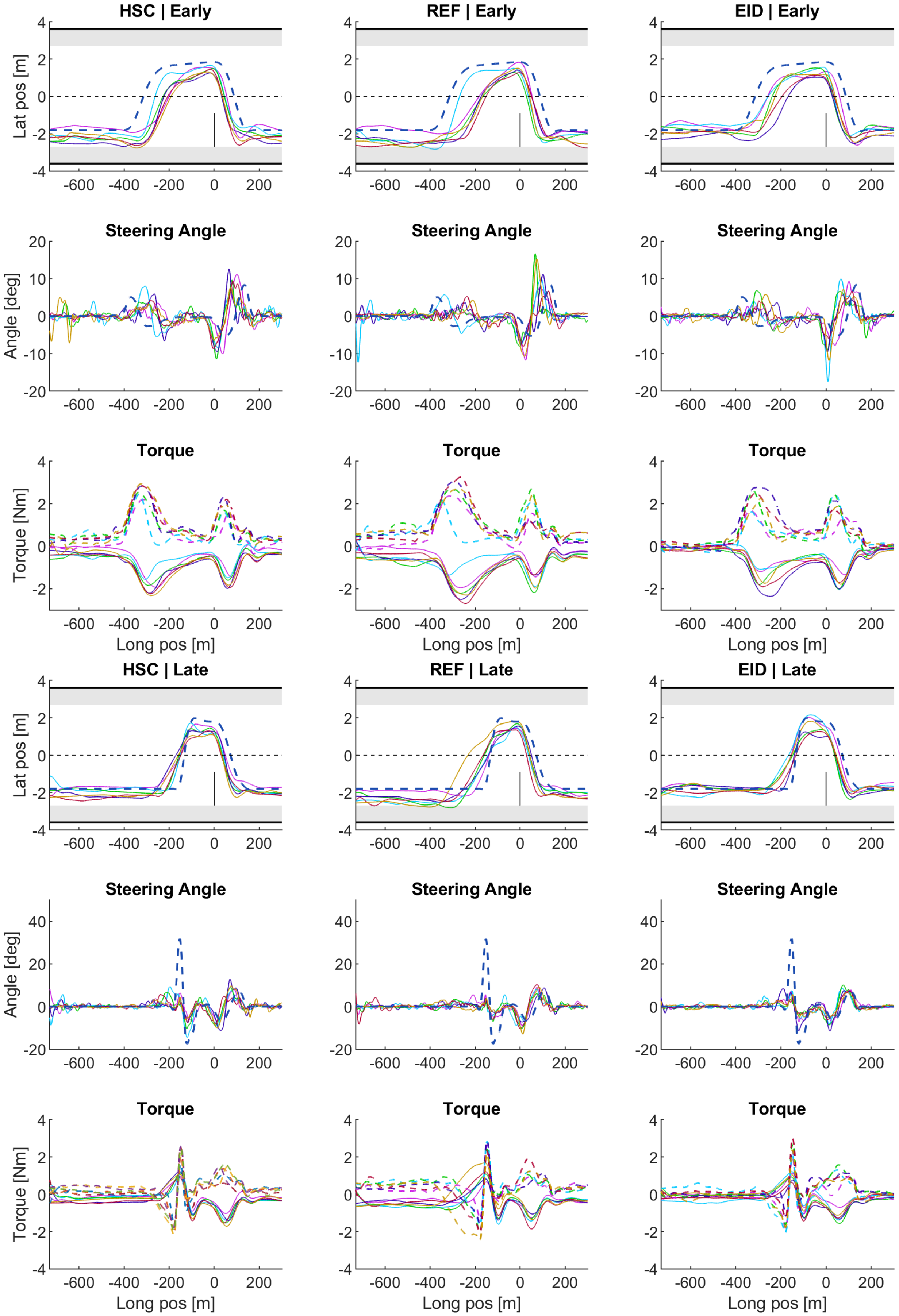
Participant 18



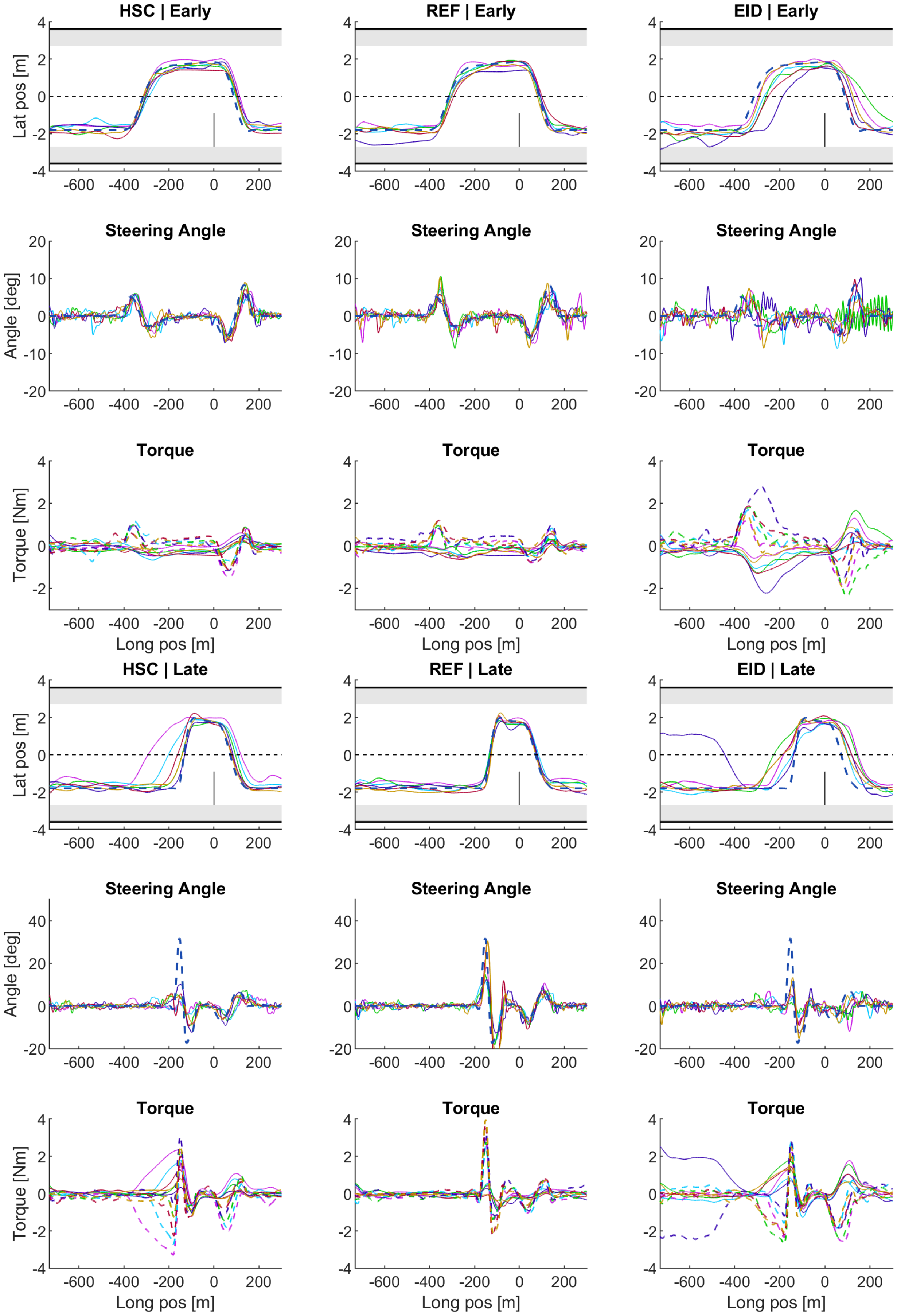
Participant 19



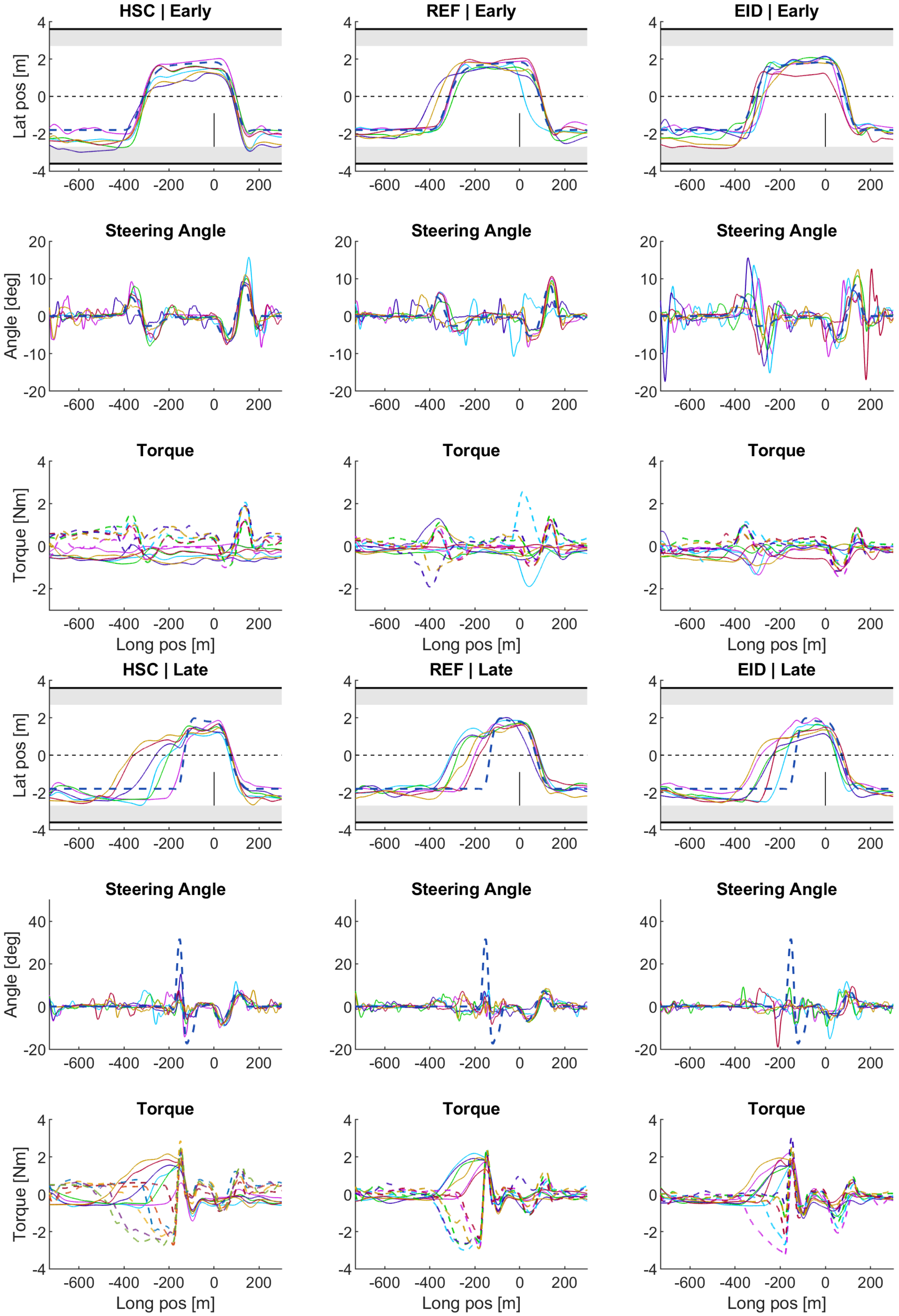
Participant 20



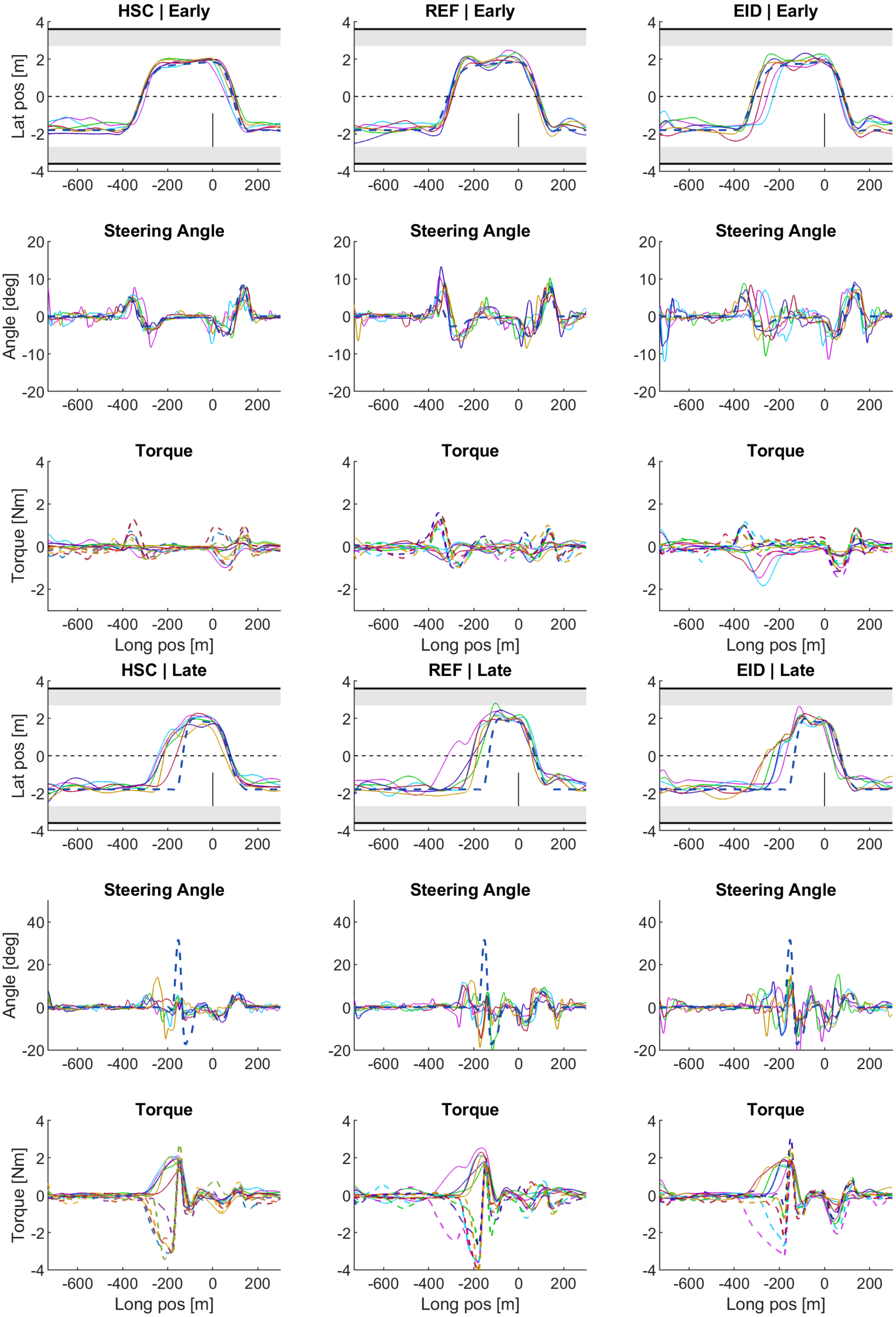
Participant 21



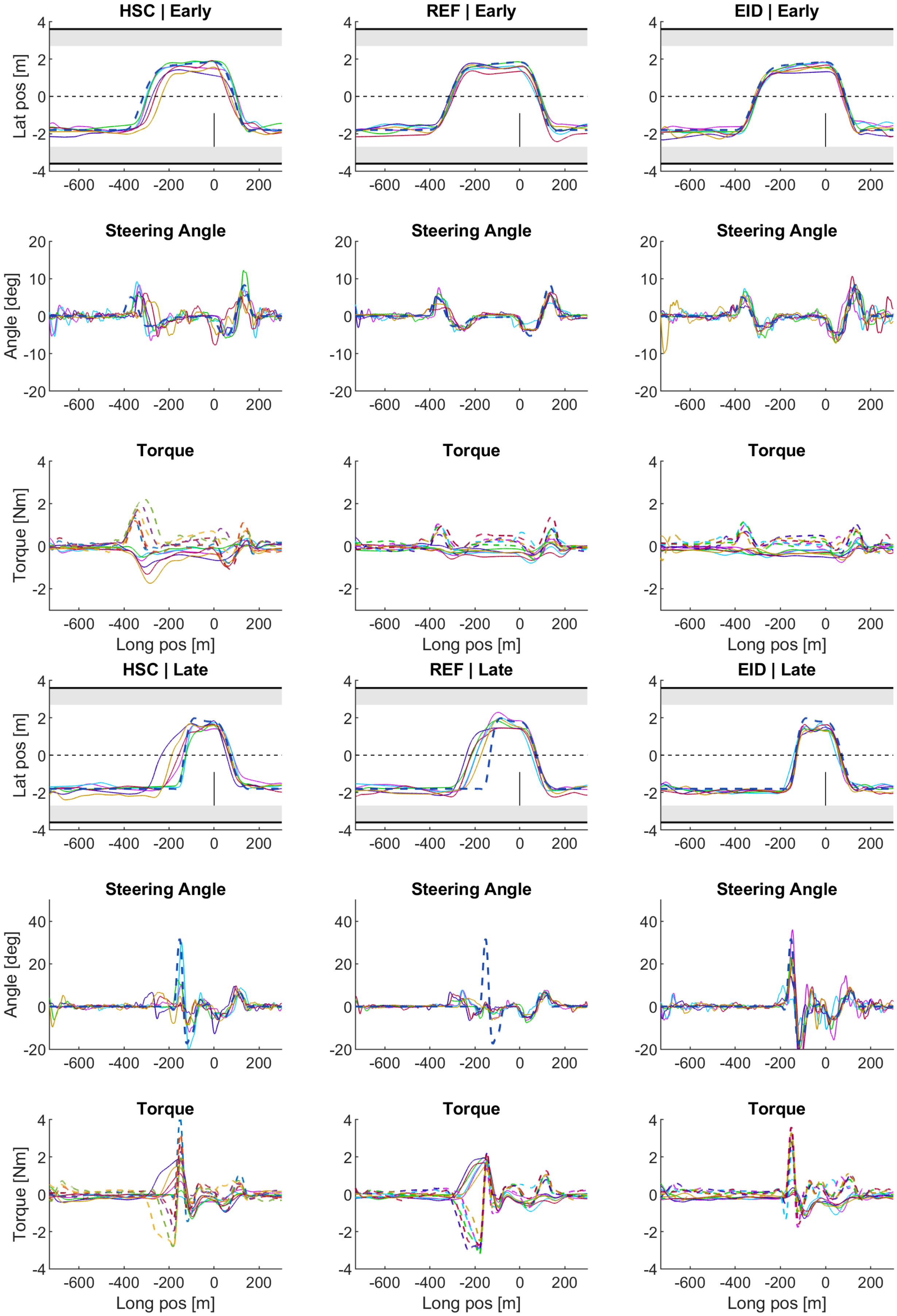
Participant 22



Participant 23



Participant 24



E

Position Based Analysis

The start of an overtake has been defined, as the first moment when:

$$y_{ego} > (y_{offset} + 0.4) \tag{E.1}$$

and

$$\psi > 0.3 \cdot max(\psi) \tag{E.2}$$

and

$$d\psi > 0 \tag{E.3}$$

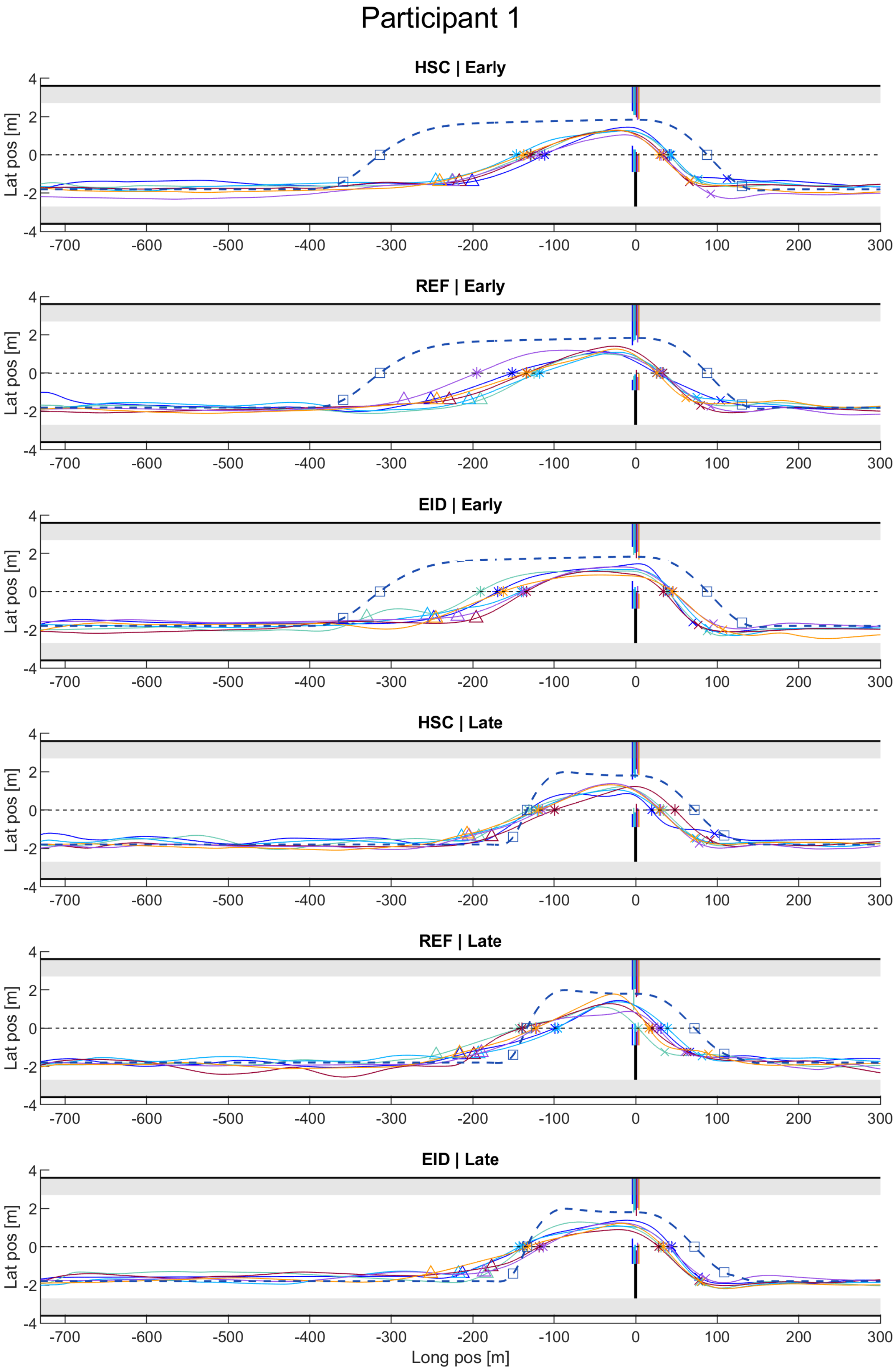
However, this method did not work robust for all driven overtakes. Therefore, some overtakes are removed from the analysis. For each driven condition at least 4 overtakes should remain. Table E.1 and E.2 show excluded overtakes. Moreover, the excluded overtakes are not visualised in position figures.

Table E.1: Early overtakes excluded

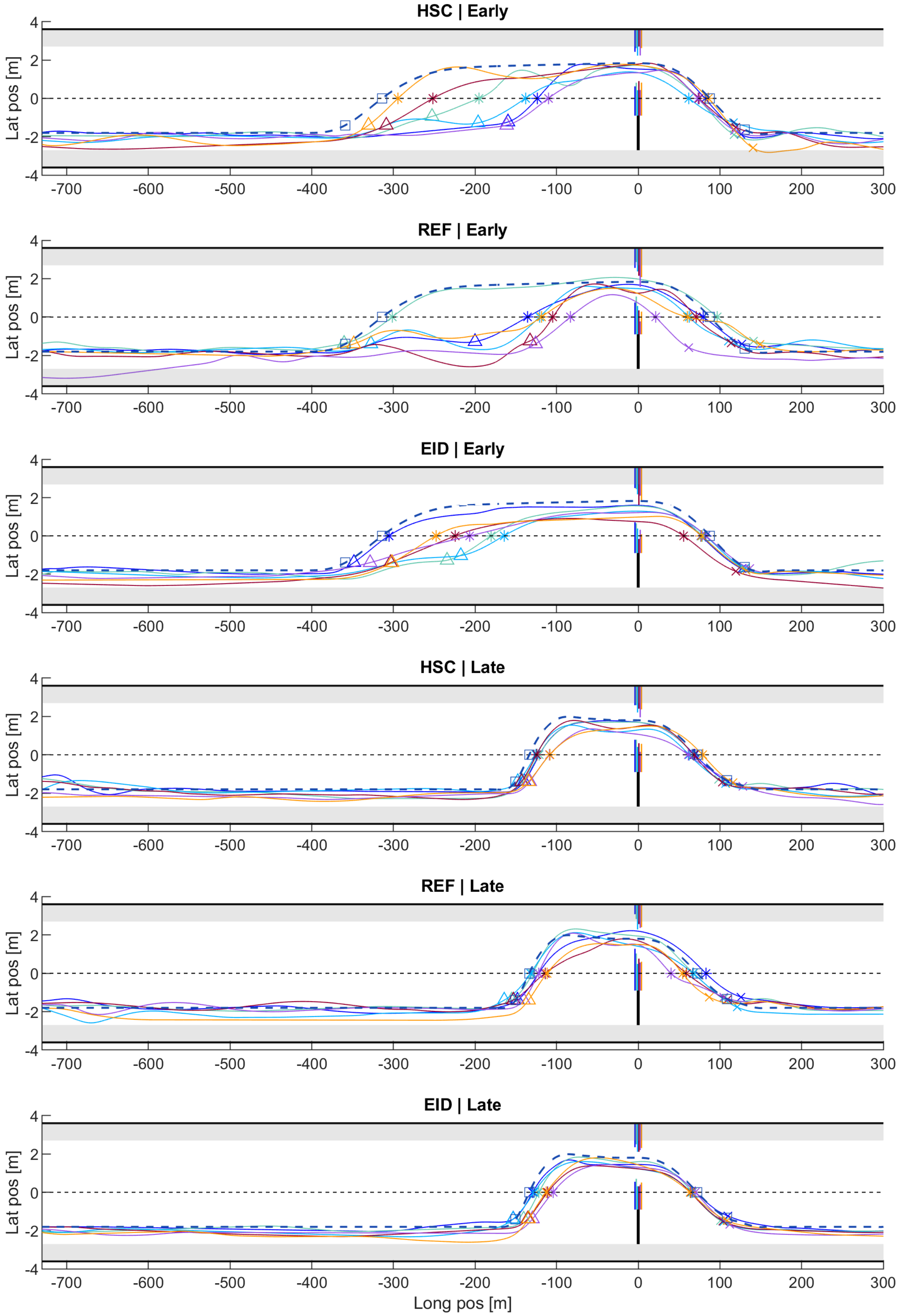
Participant	Condition	Repetition
4	EID	4
9	REF	4,6
14	REF	2

Table E.2: Late overtakes excluded

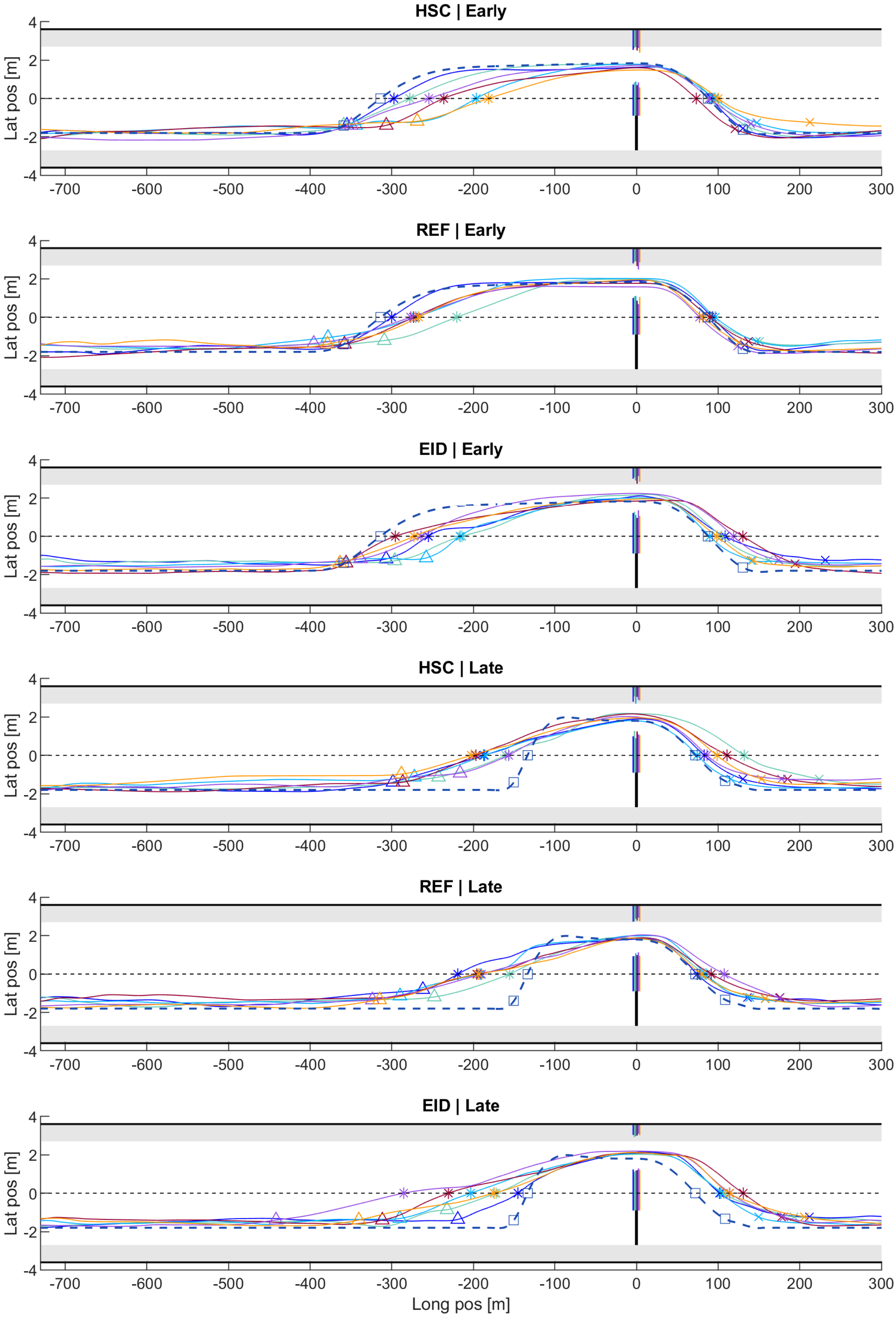
Participant	Condition	Repetition
1	HSC	1
3	REF	4
4	EID	1
5	HSC	5
6	HSC	1,5
7	HSC	1
8	HSC,REF,EID	1,5,2
11	REF	1
14	HSC	3
17	REF	1
19	EID	1


Participant 1
HSC | Early
REF | Early
EID | Early
HSC | Late
REF | Late
EID | Late
Lat pos [m]
4
2
0
-2
-4
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]

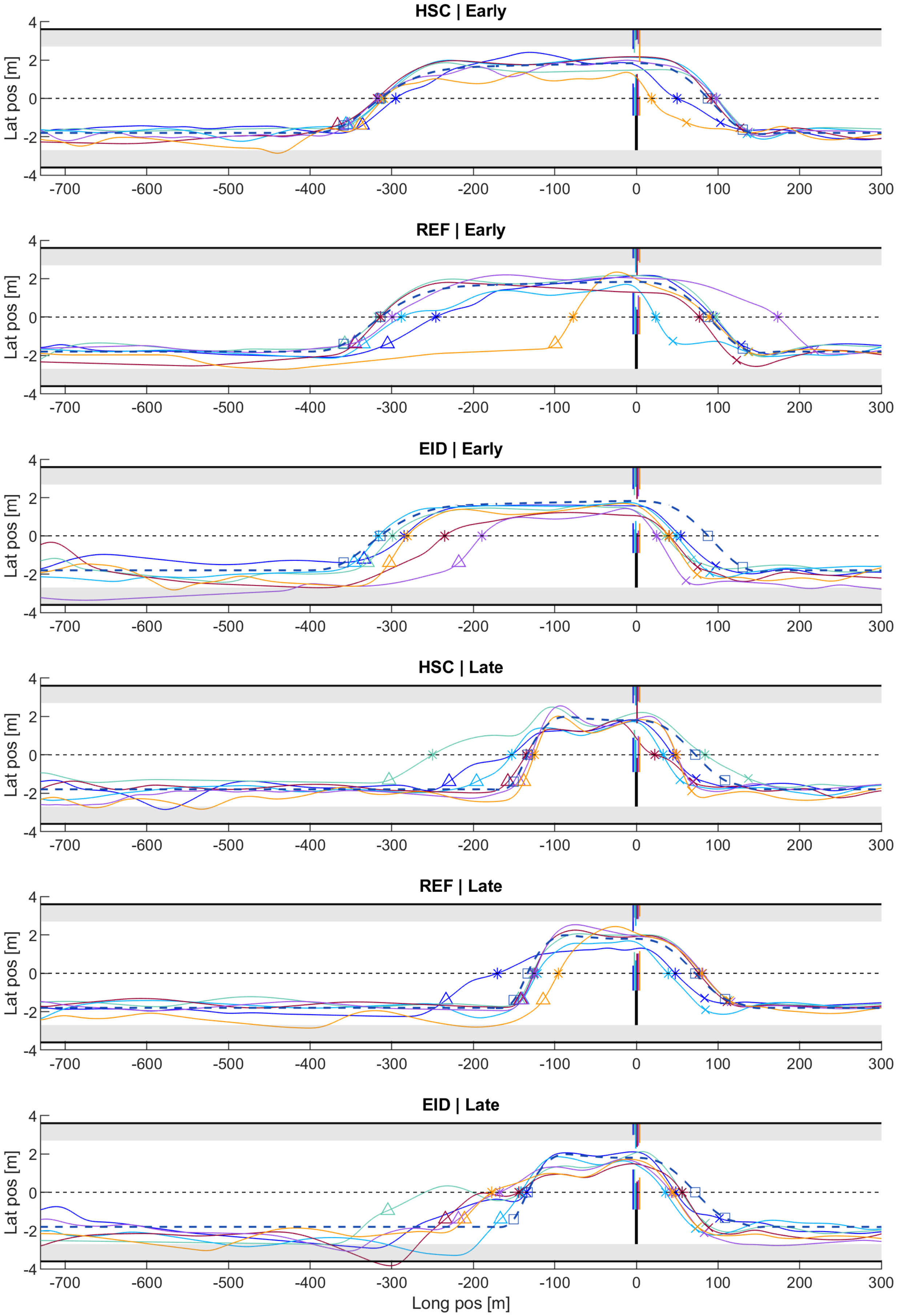
Participant 2



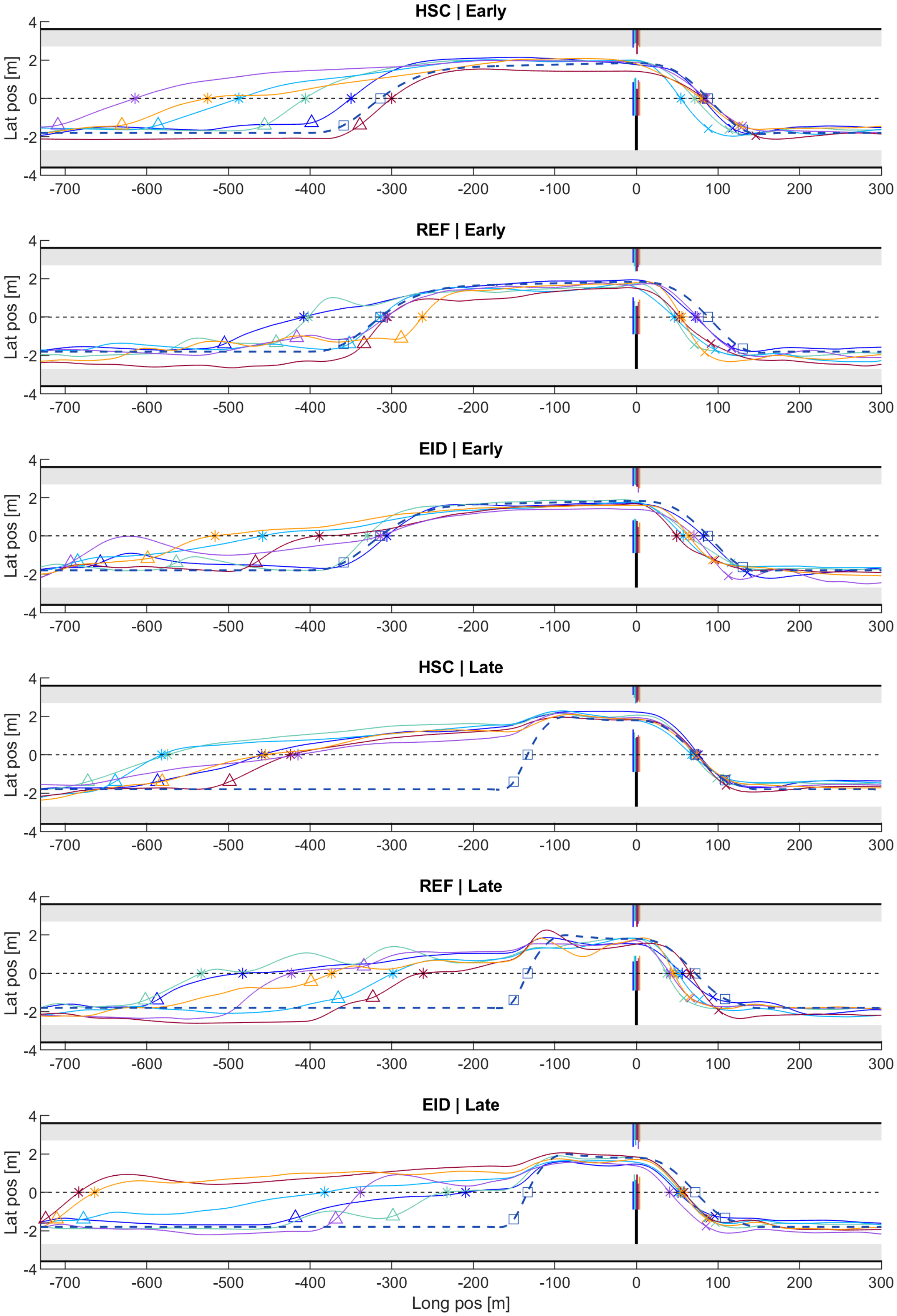
Participant 3



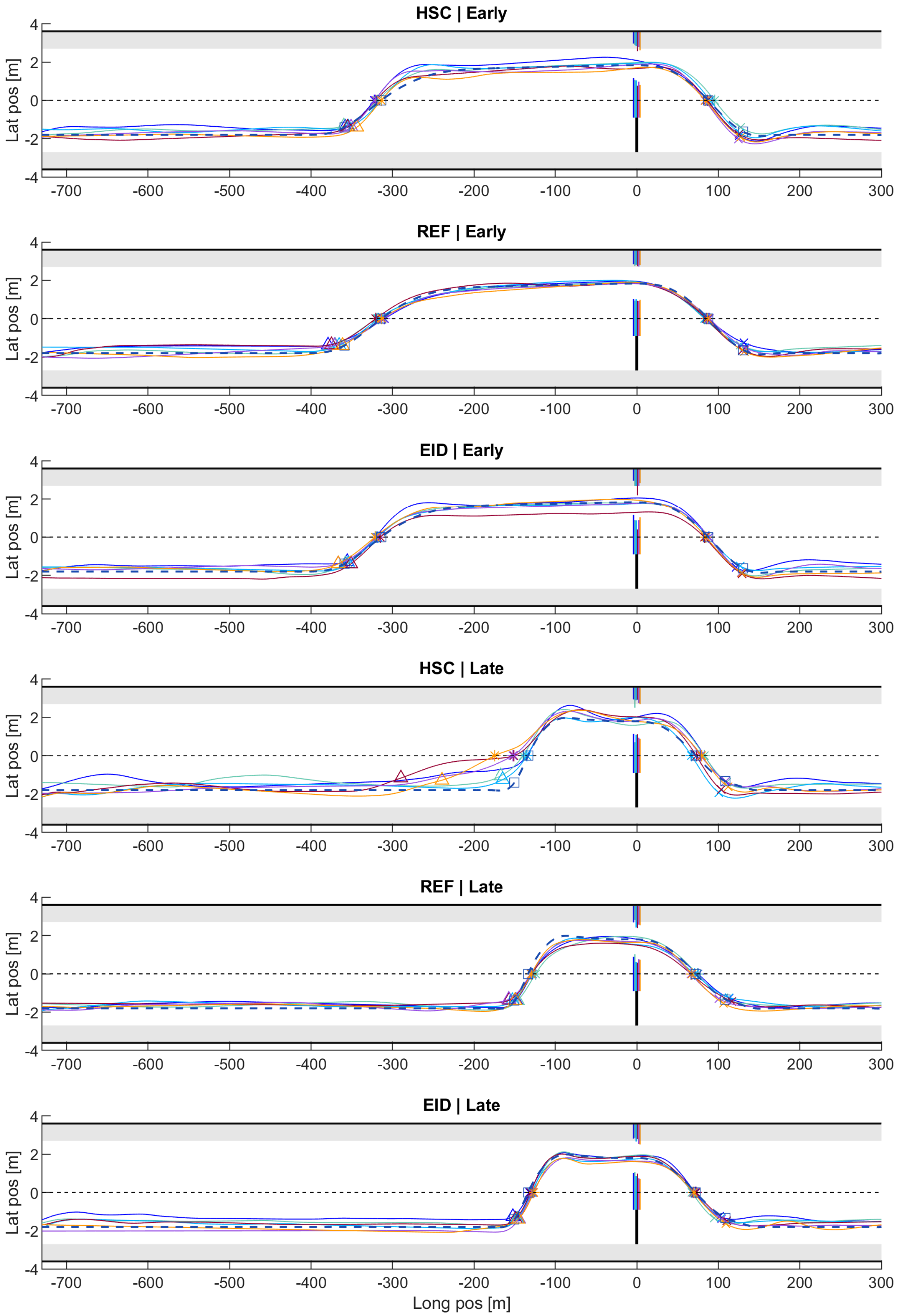
Participant 4



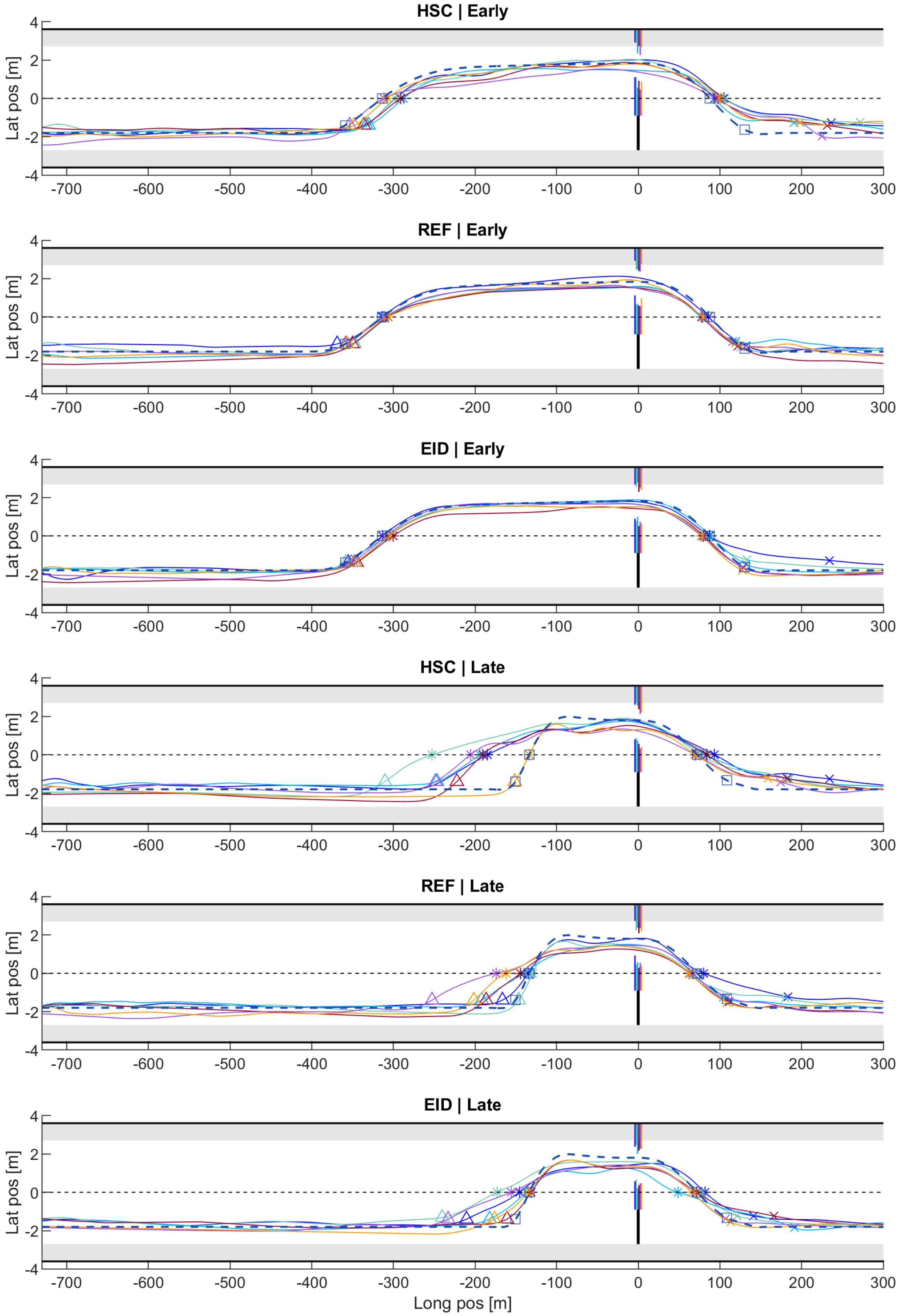
Participant 5



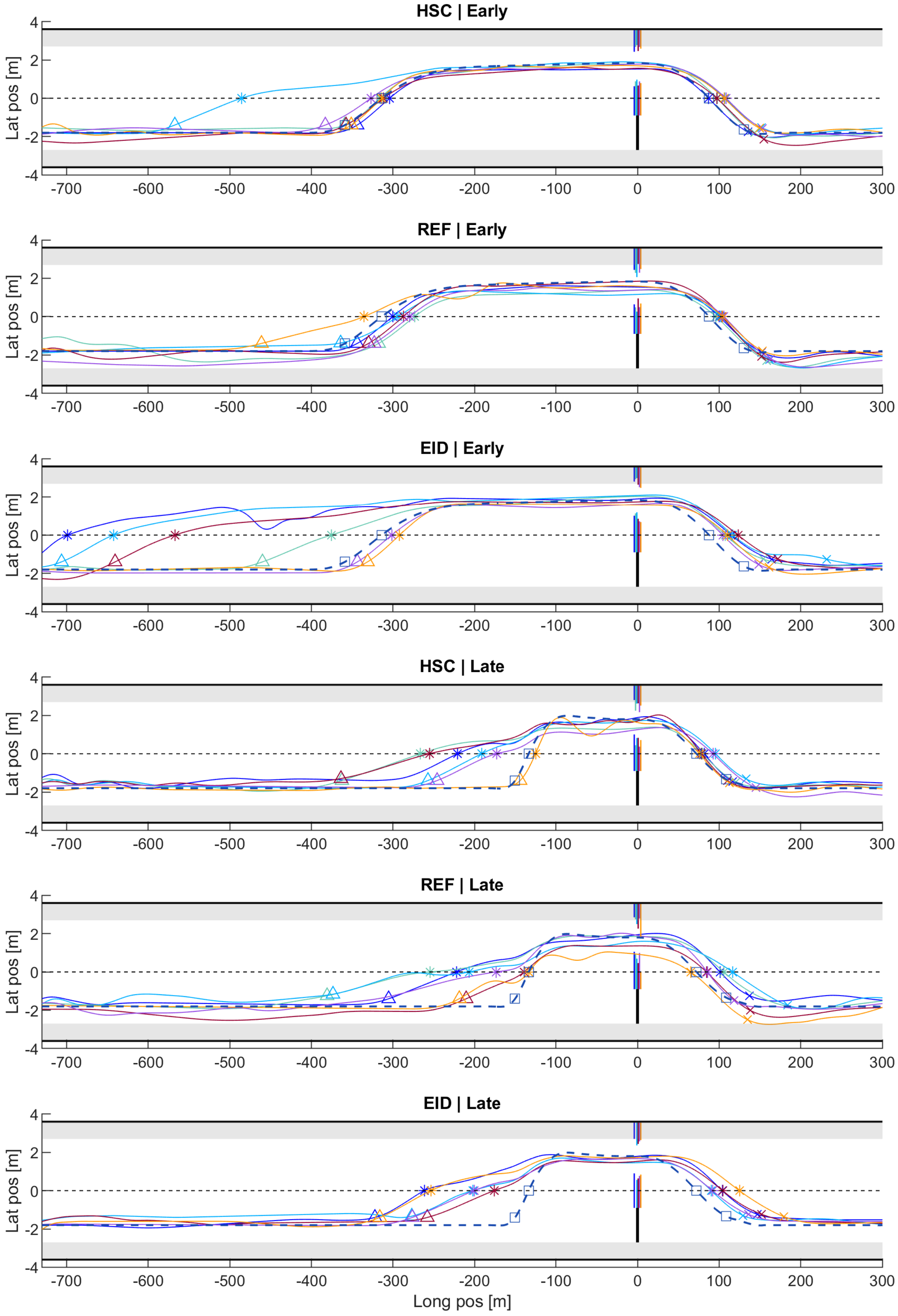
Participant 6



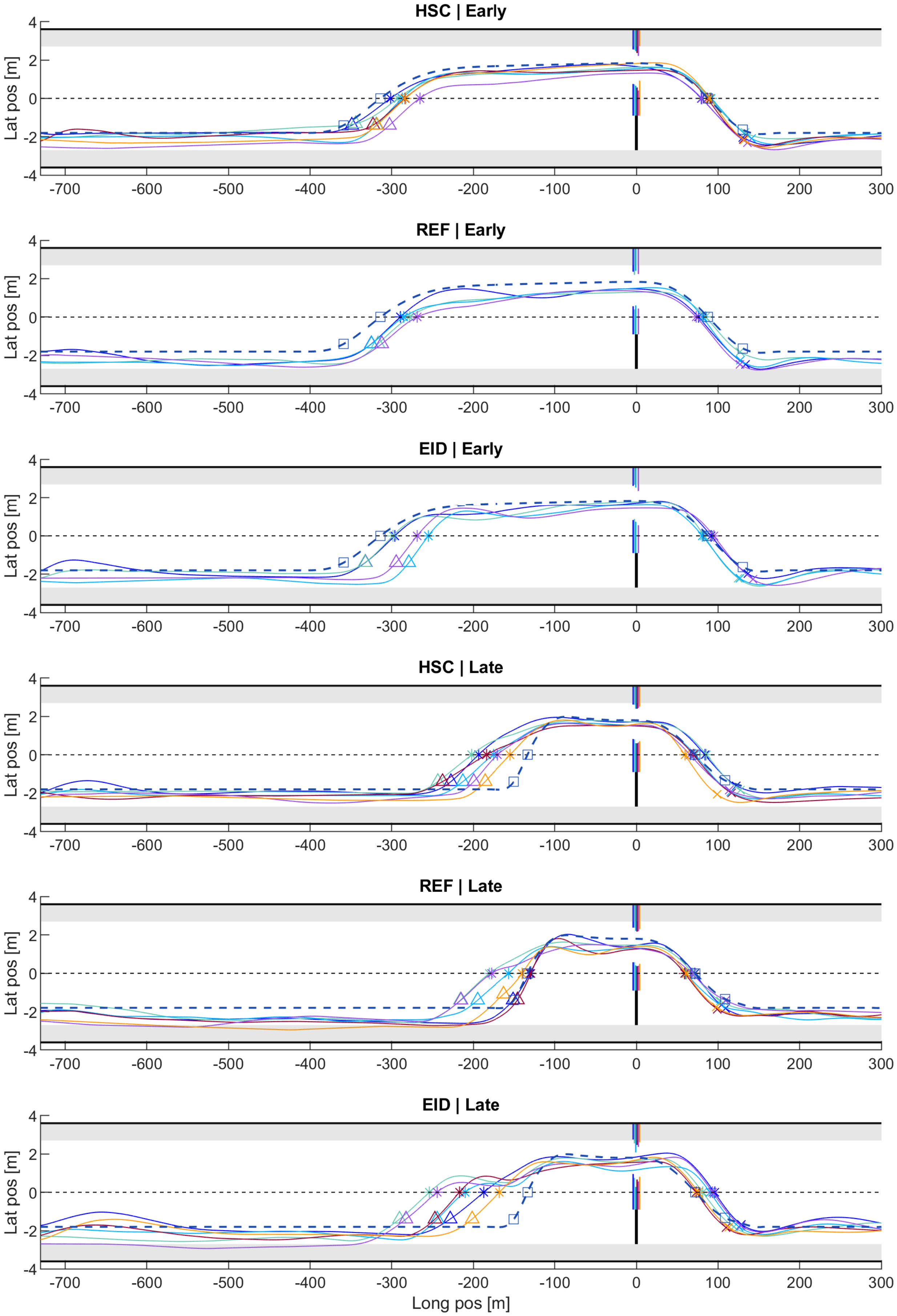
Participant 7



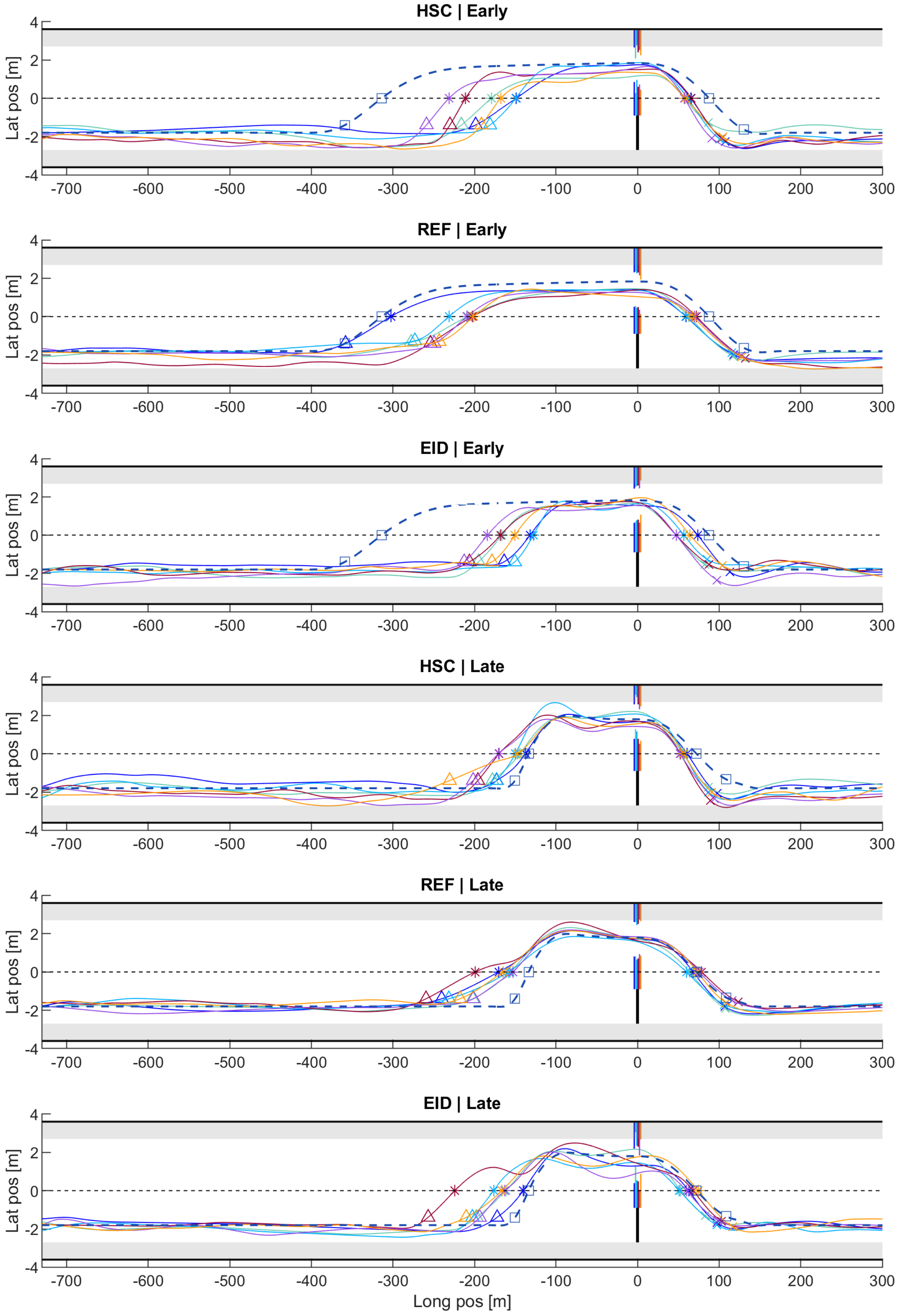
Participant 8



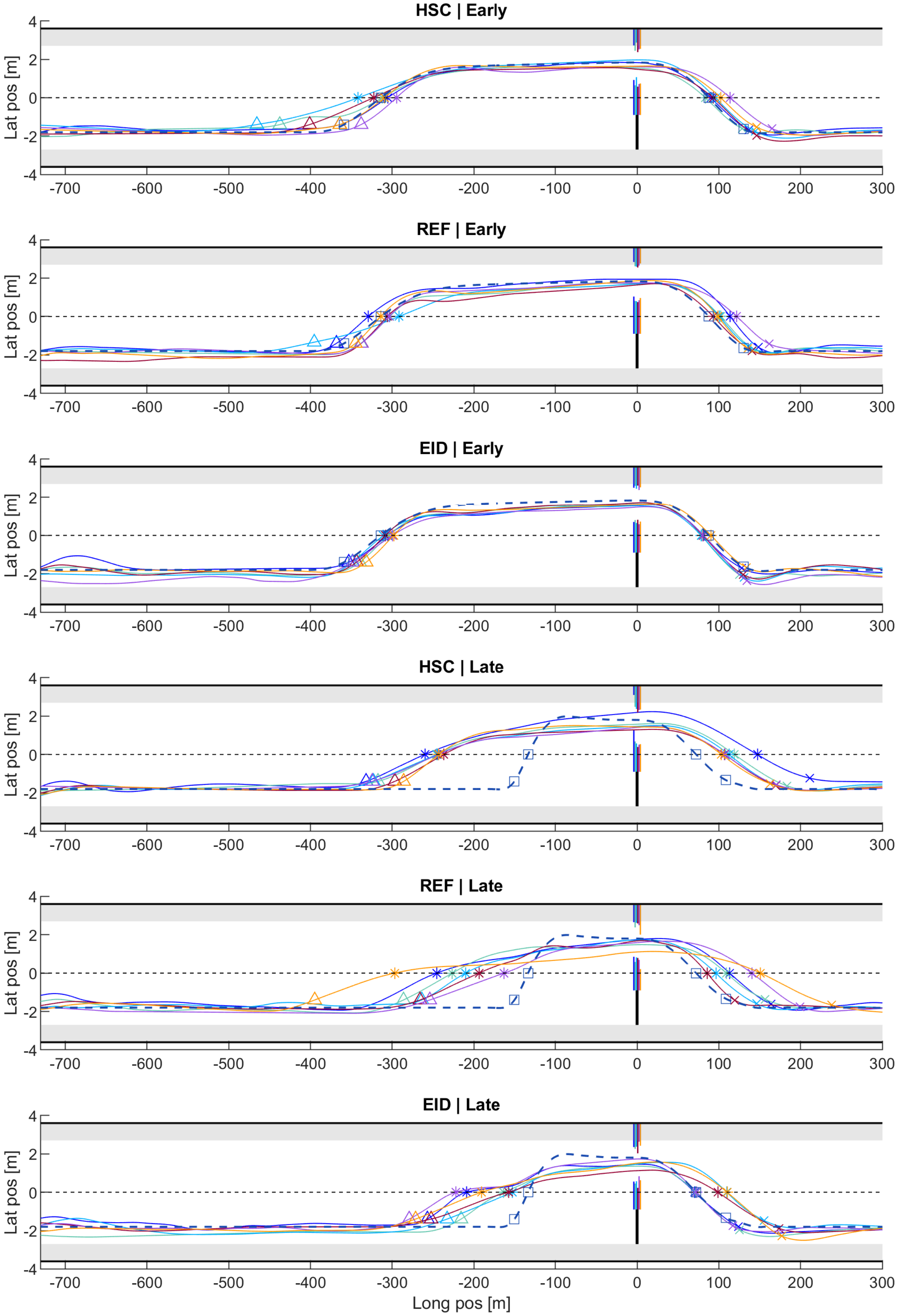
Participant 9



Participant 10



Participant 11



HSC | Early

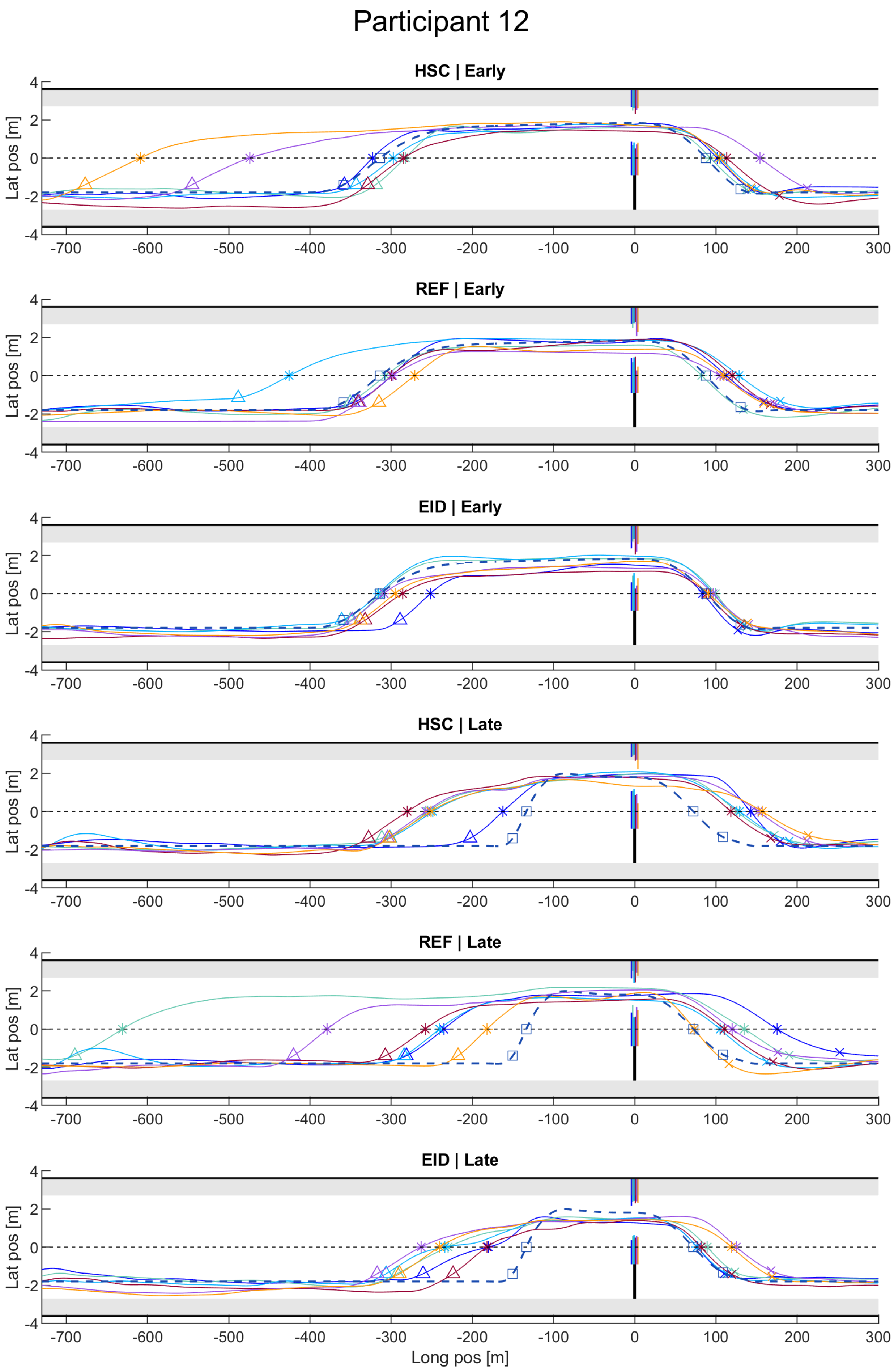
REF | Early

EID | Early

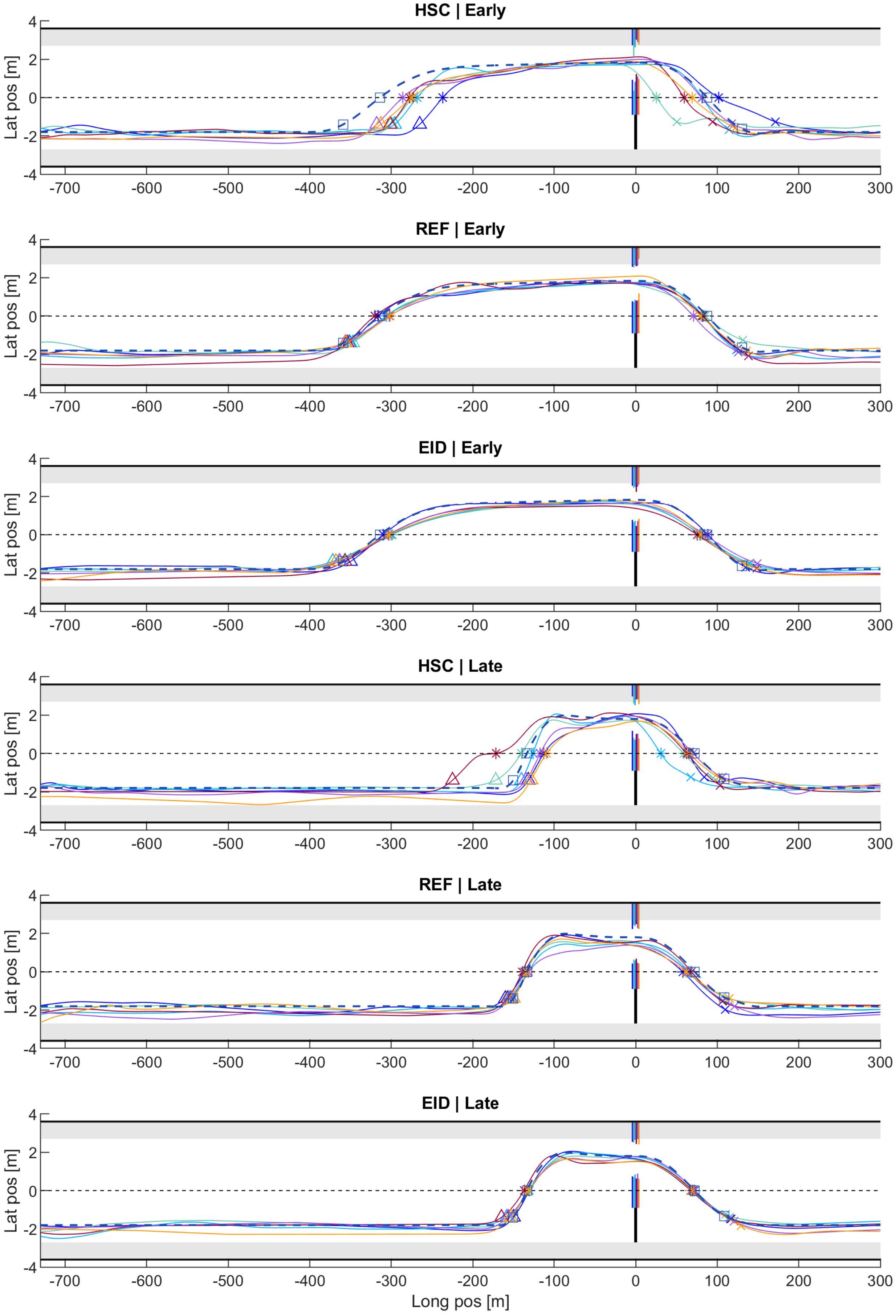
HSC | Late

REF | Late

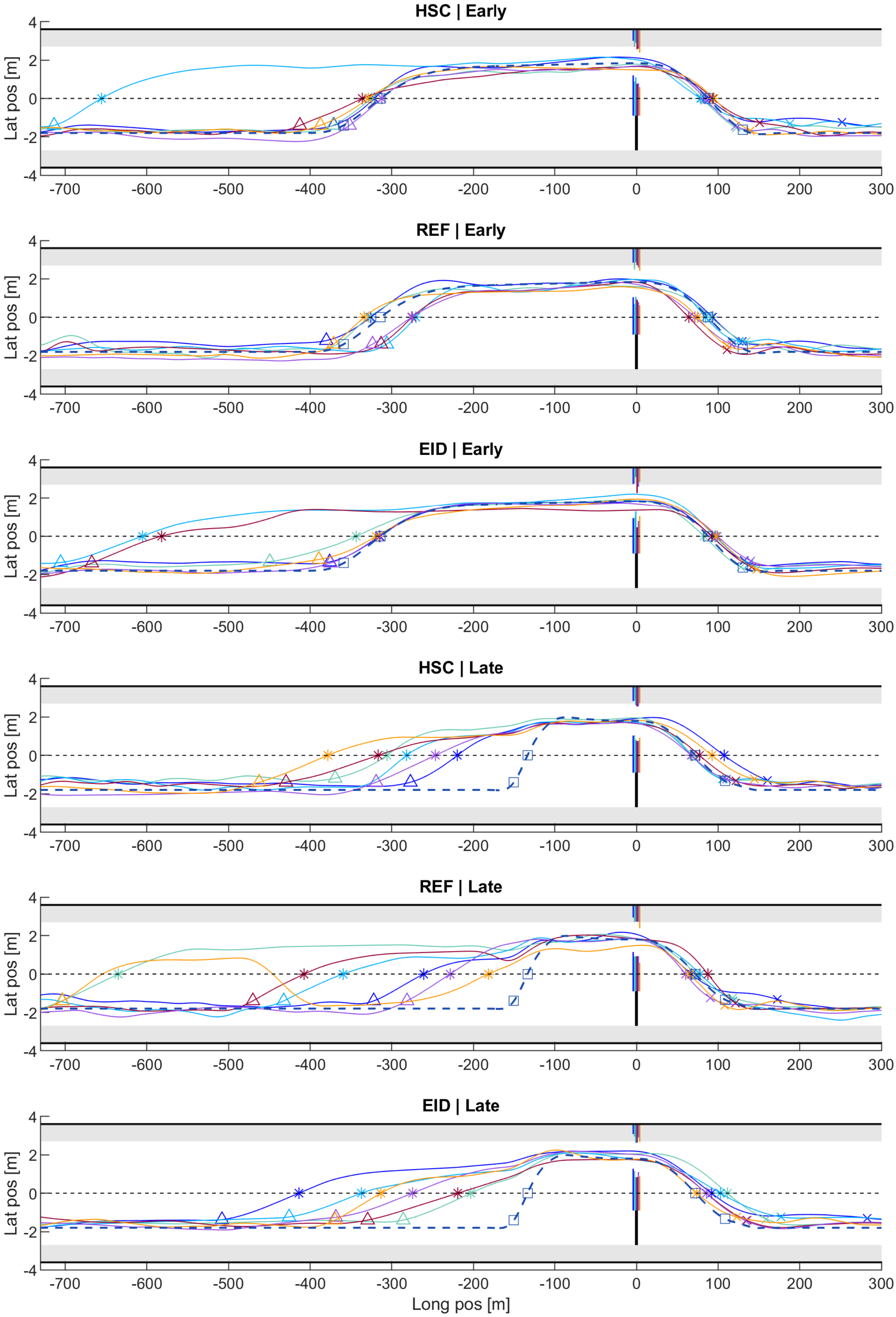
EID | Late


Participant 12
HSC | Early
REF | Early
EID | Early
HSC | Late
REF | Late
EID | Late
Lat pos [m]
4
2
0
-2
-4
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]

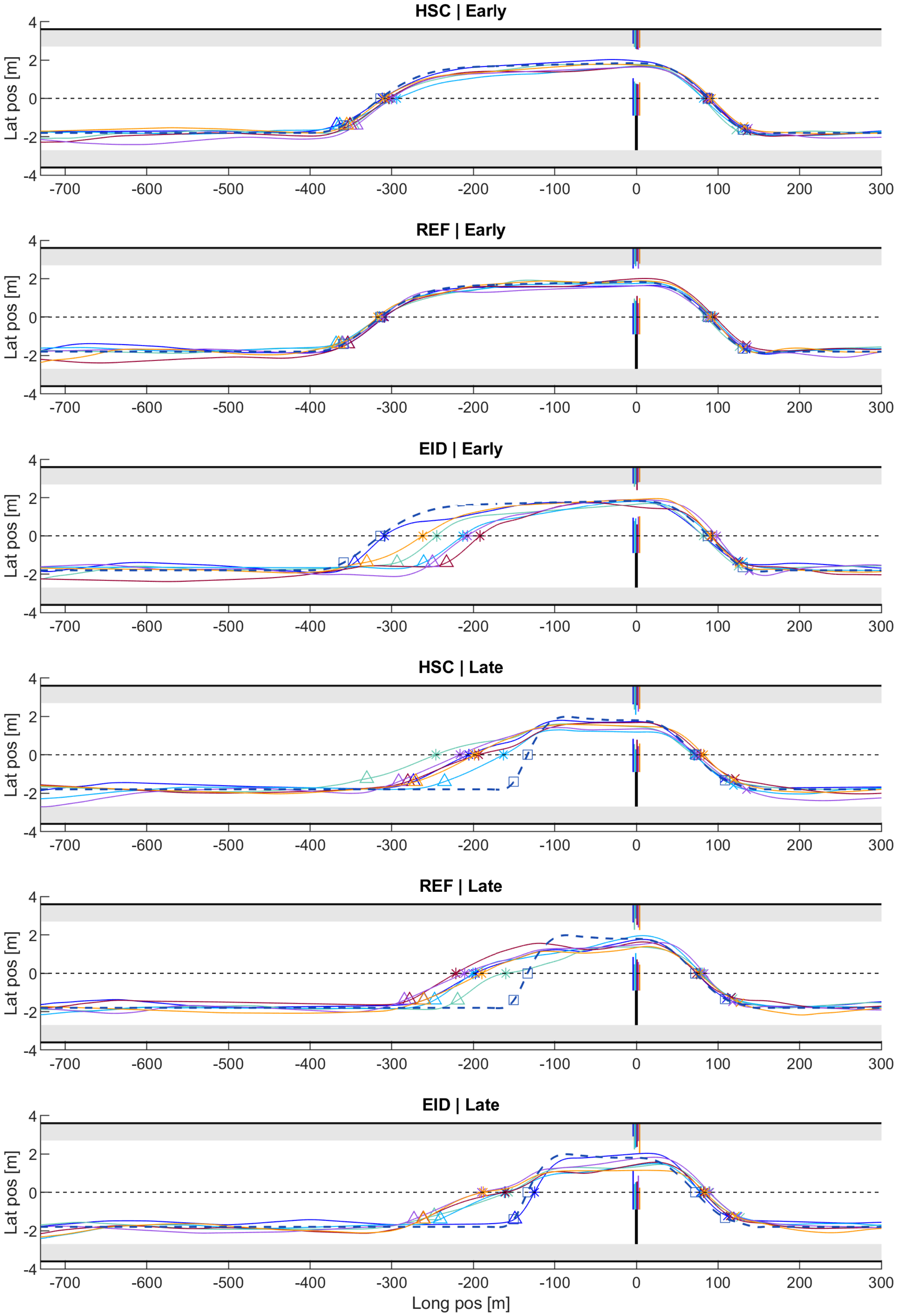
Participant 13



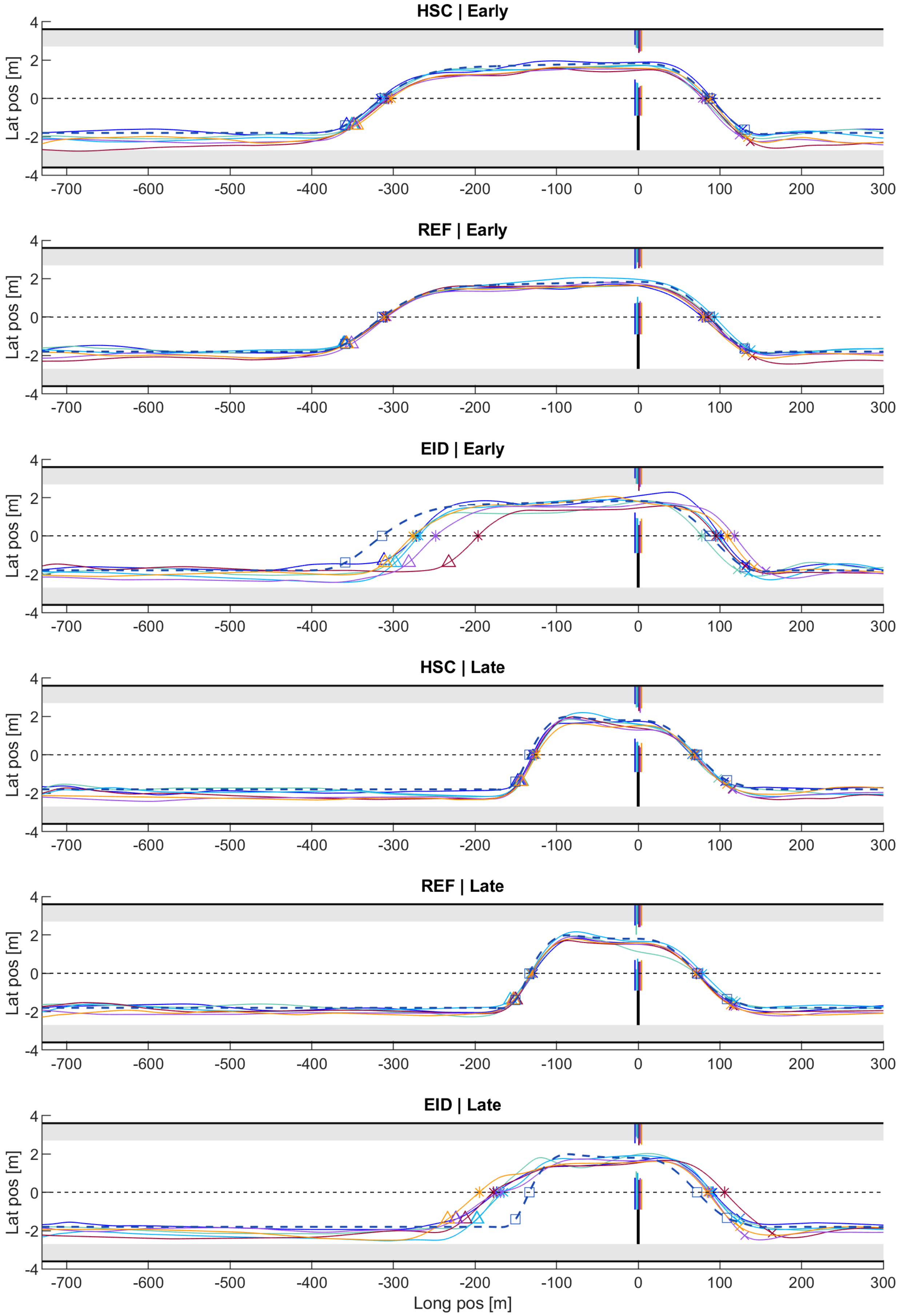
Participant 14

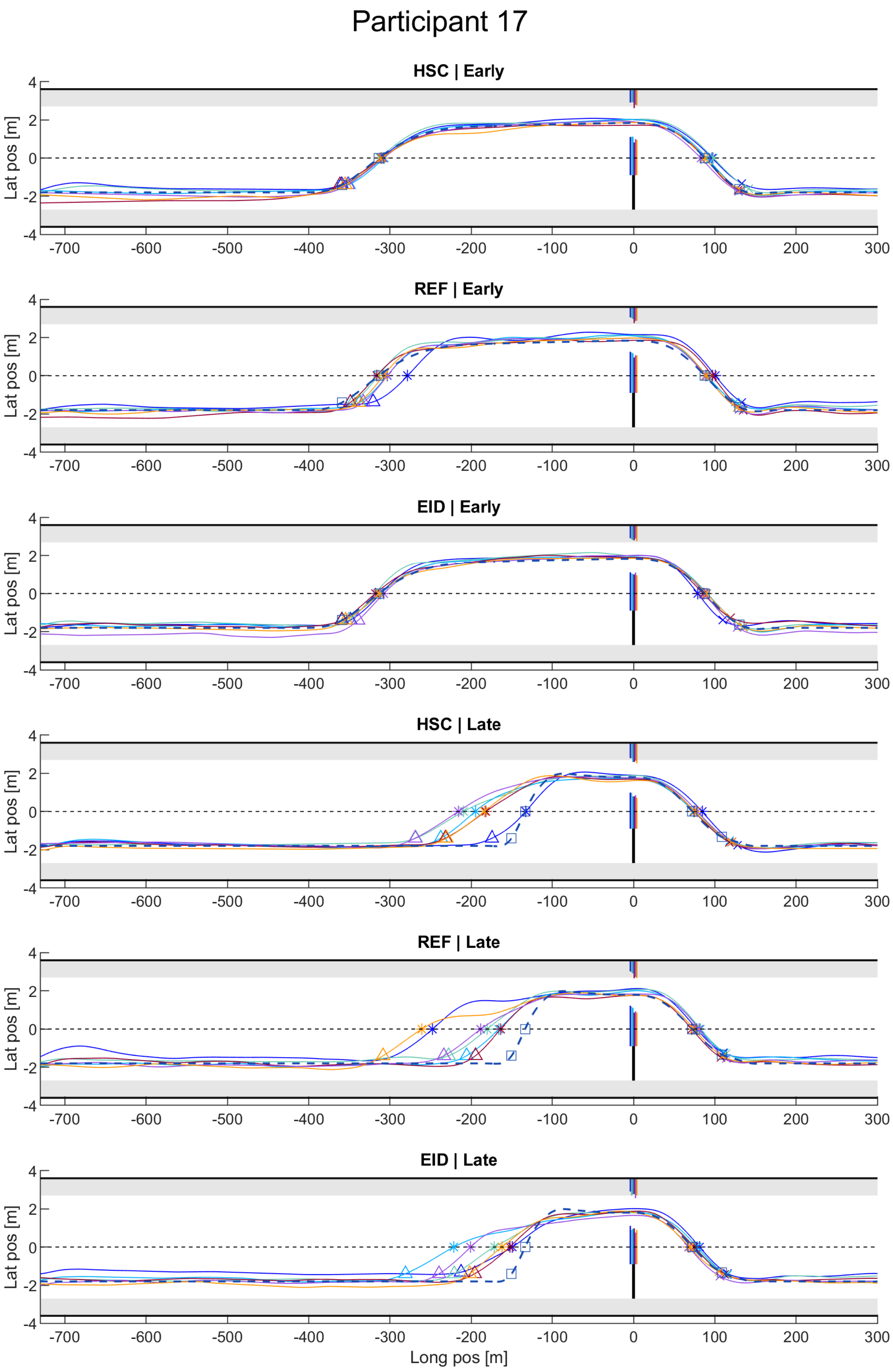


Participant 15

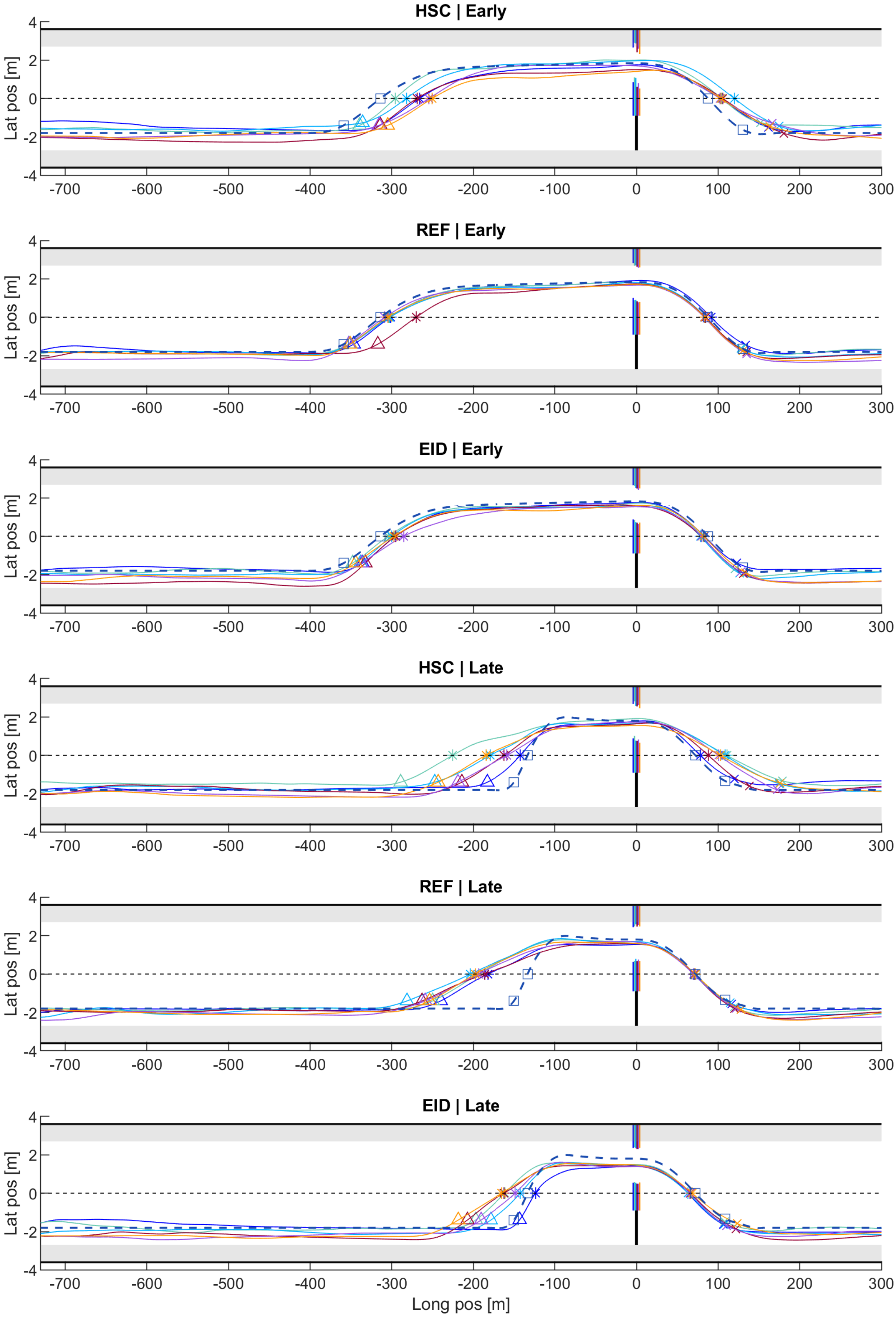


Participant 16

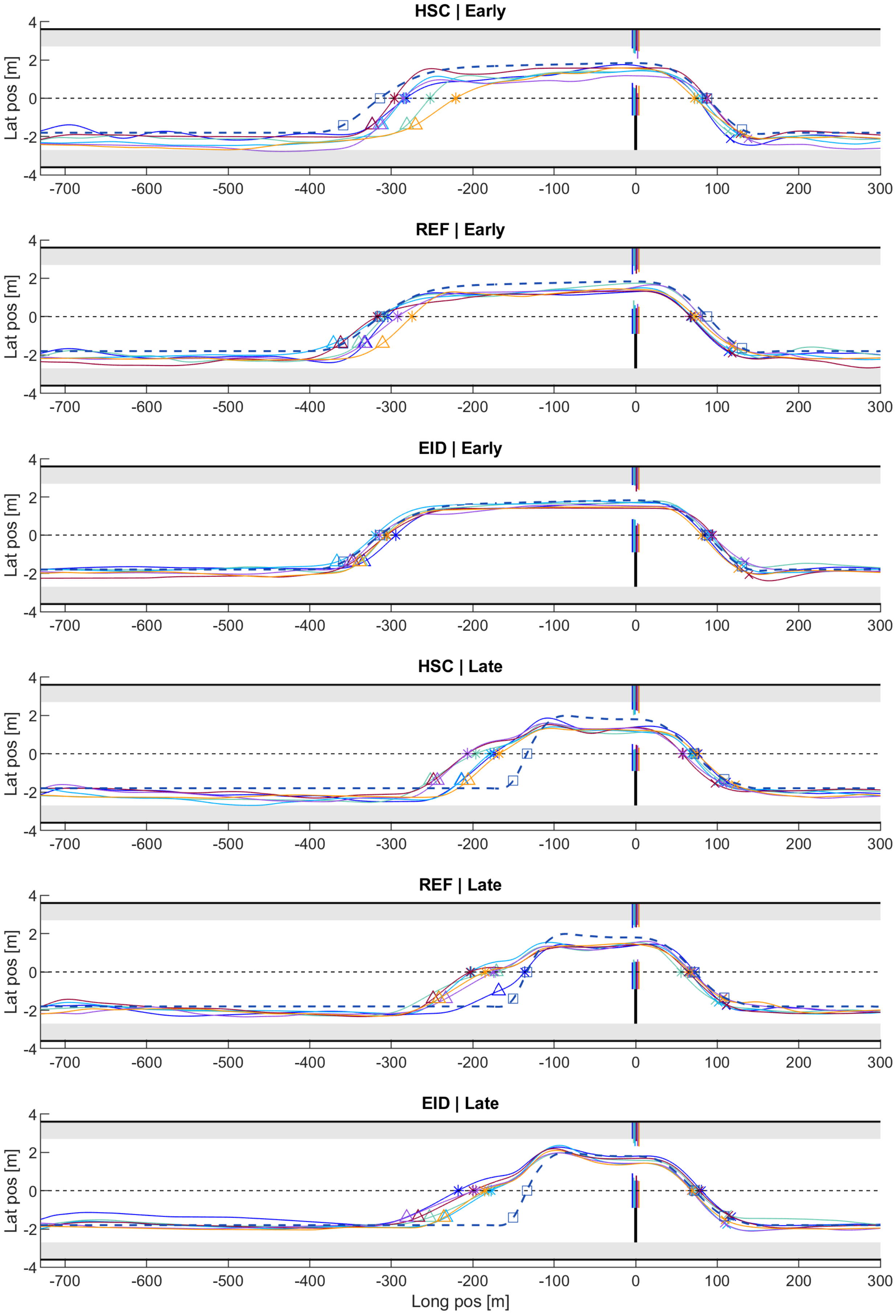


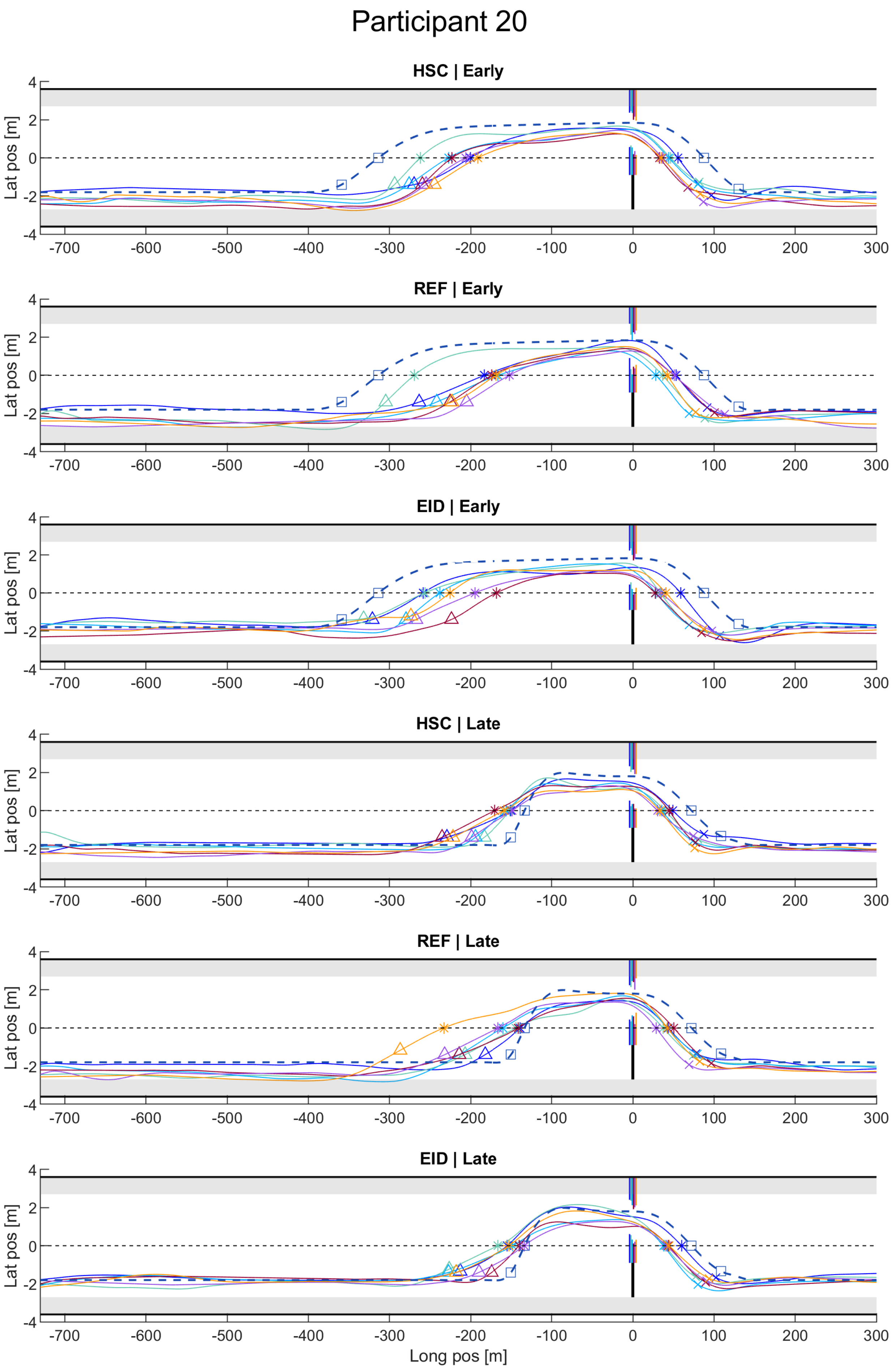

Participant 17
HSC | Early
REF | Early
EID | Early
HSC | Late
REF | Late
EID | Late
Lat pos [m]
4
2
0
-2
-4
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]

Participant 18

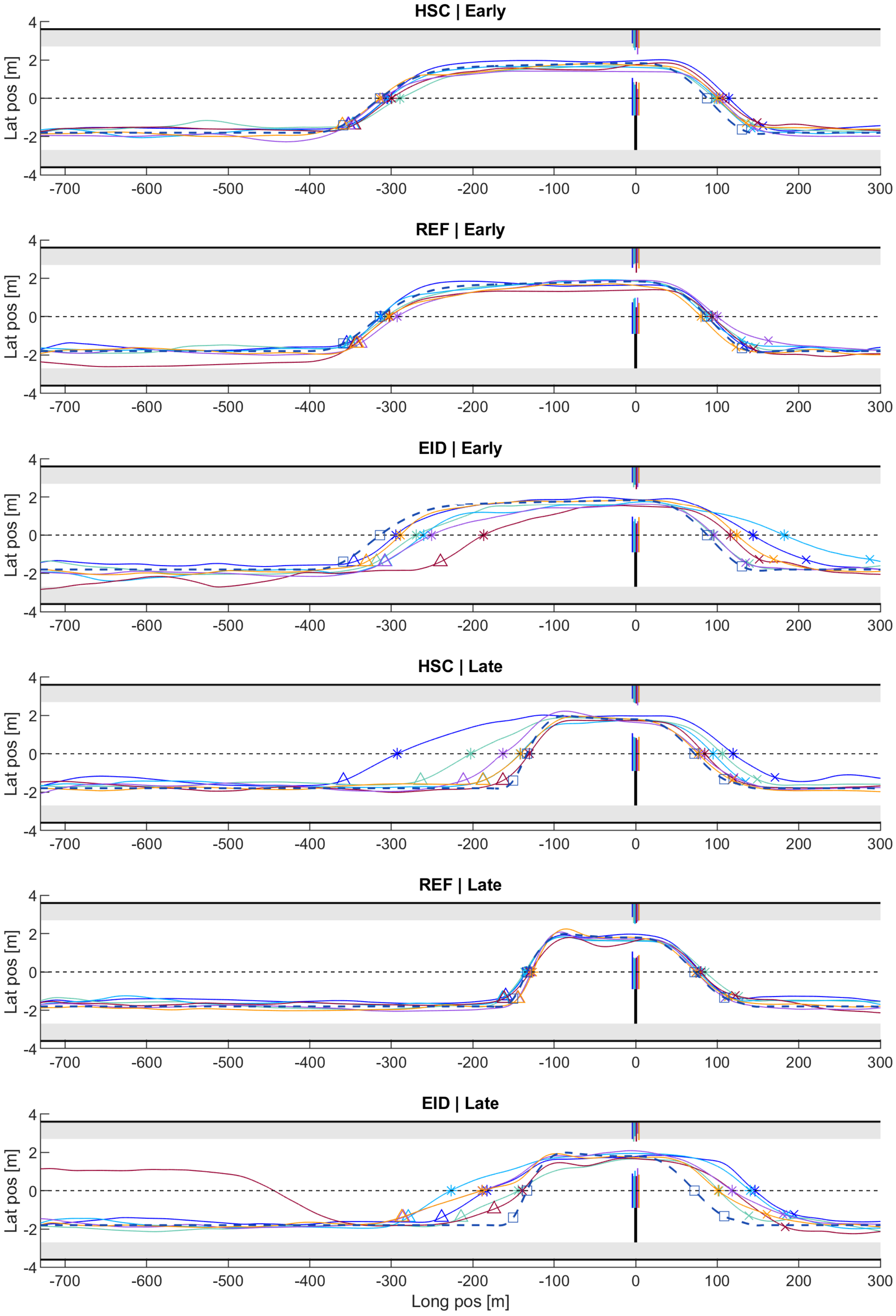


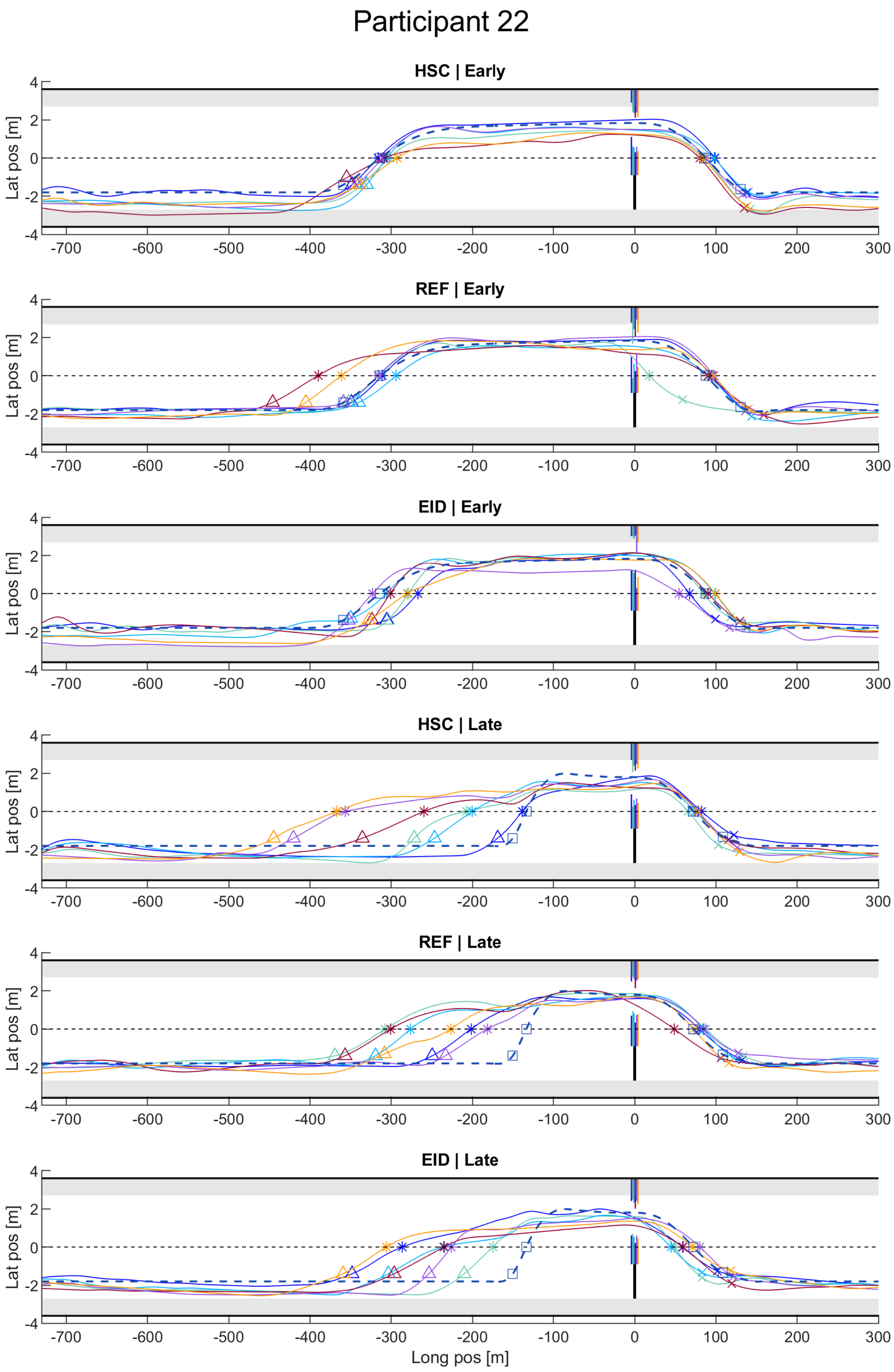
Participant 19



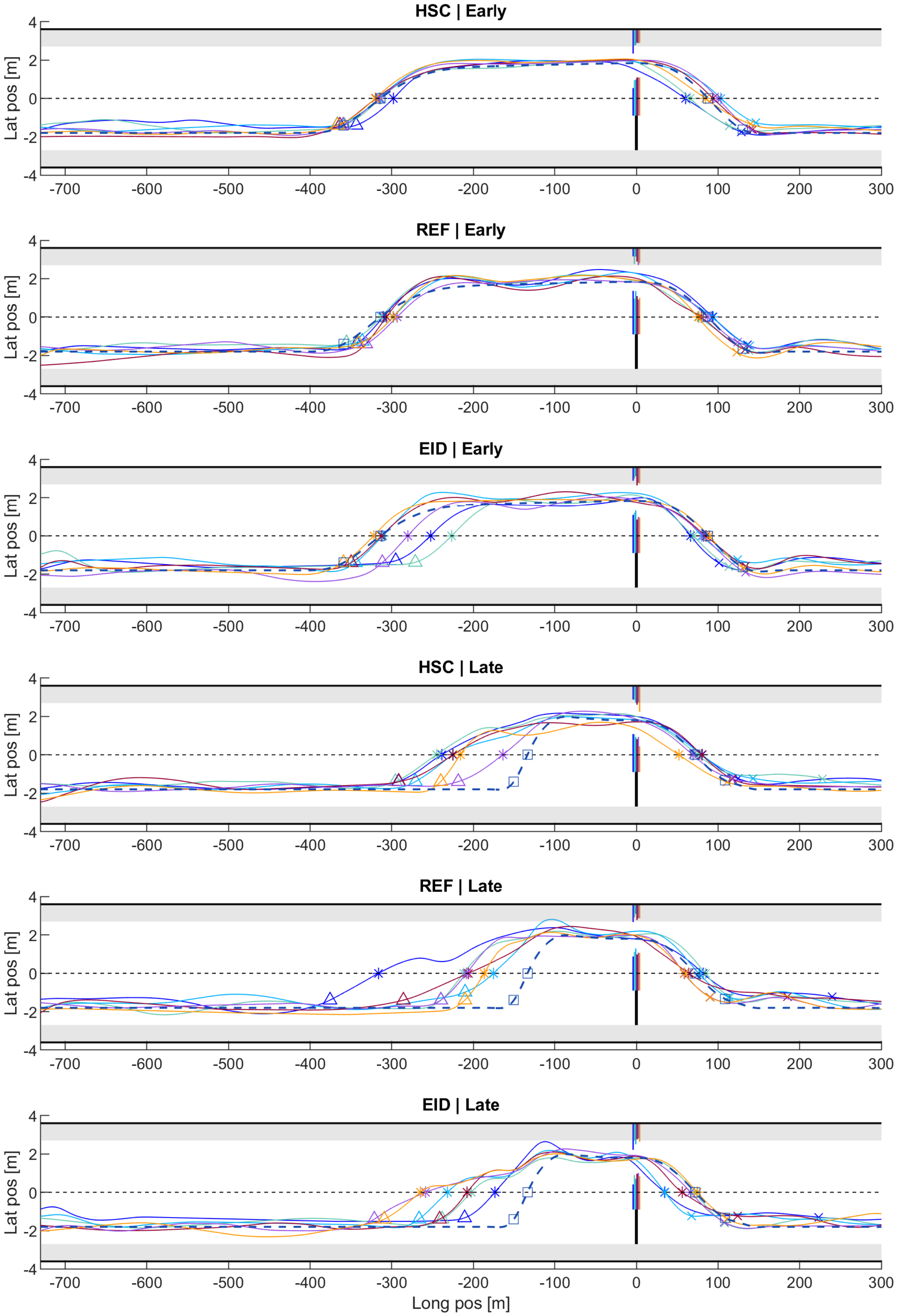

Participant 20
HSC | Early
REF | Early
EID | Early
HSC | Late
REF | Late
EID | Late
Lat pos [m]
4
2
0
-2
-4
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]

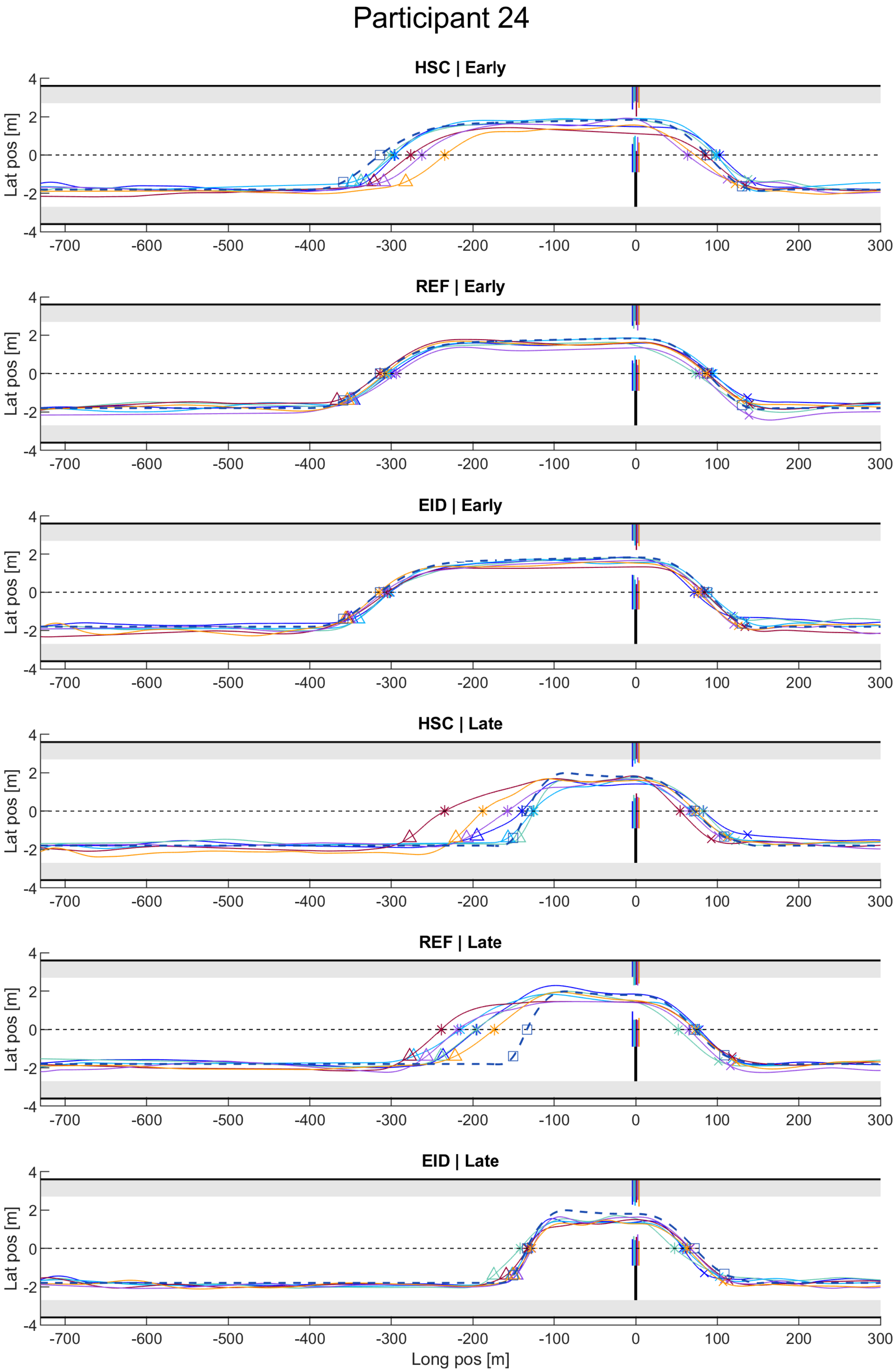
Participant 21




Participant 22
HSC | Early
REF | Early
EID | Early
HSC | Late
REF | Late
EID | Late
Lat pos [m]
4
2
0
-2
-4
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]

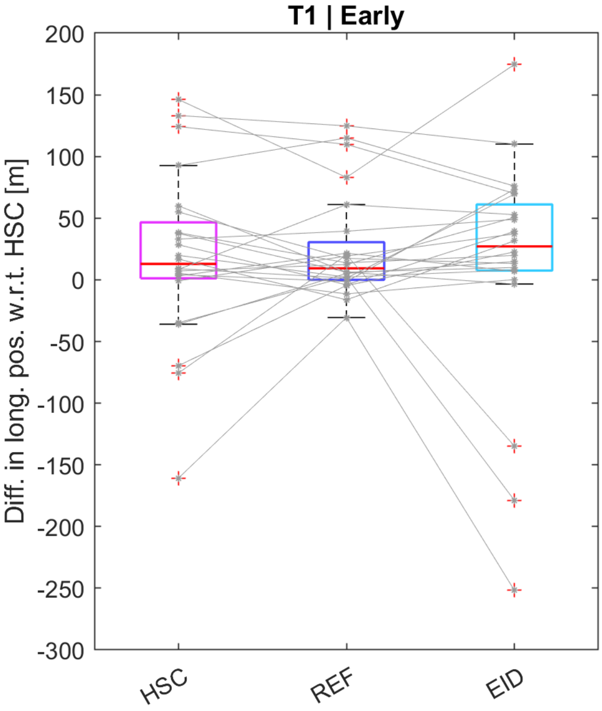
Participant 23

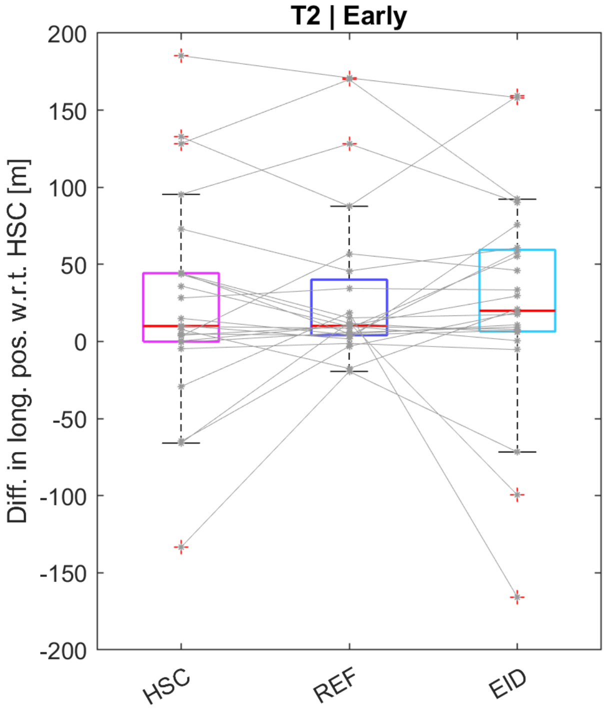


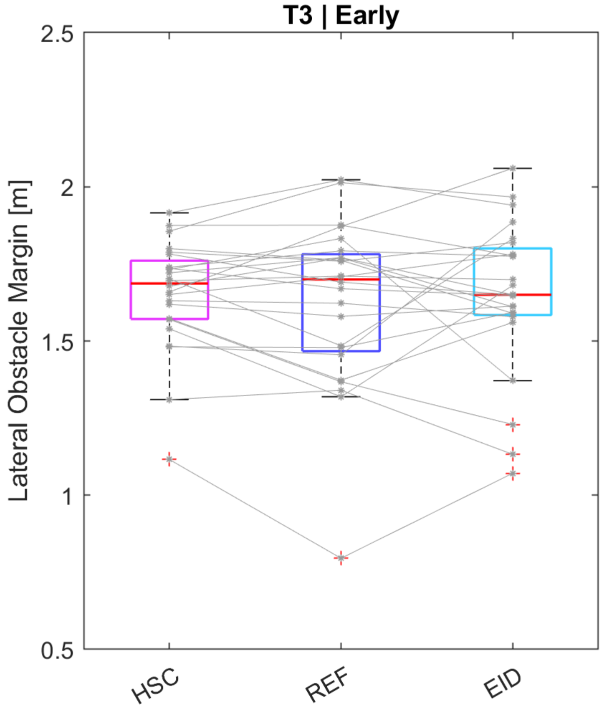

Participant 24
HSC | Early
REF | Early
EID | Early
HSC | Late
REF | Late
EID | Late
Lat pos [m]
4
2
0
-2
-4
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]

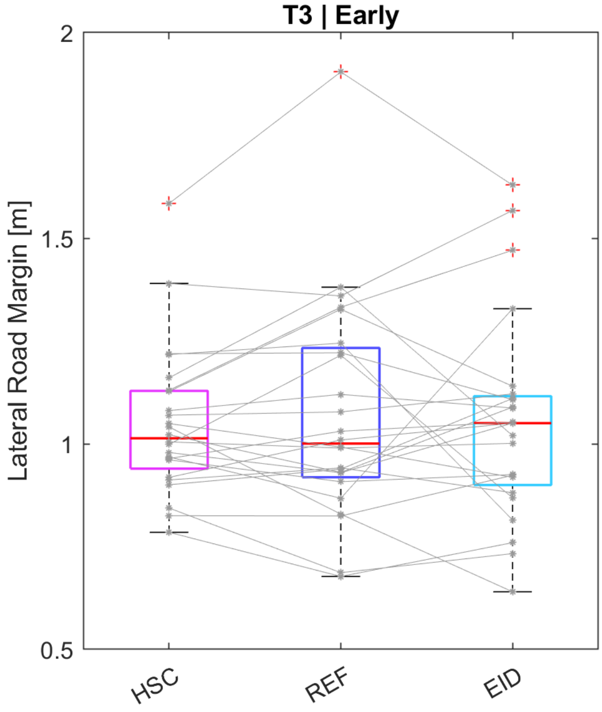
Position Based Measures

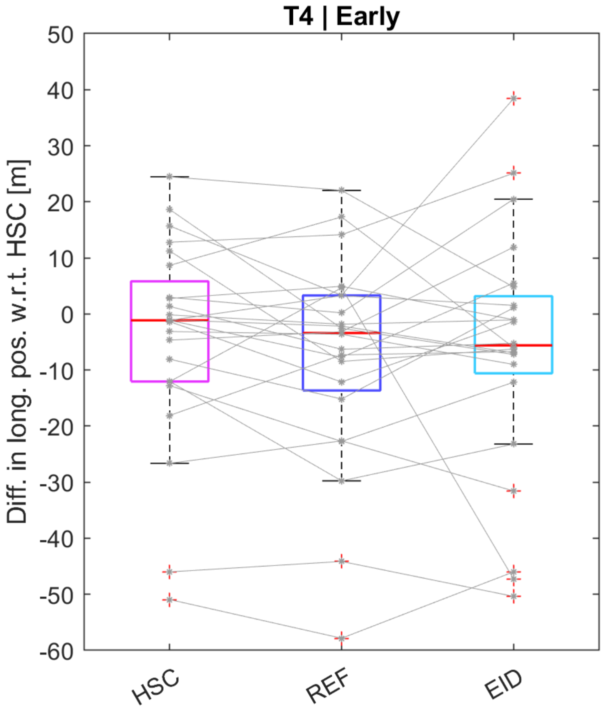
Early overtake

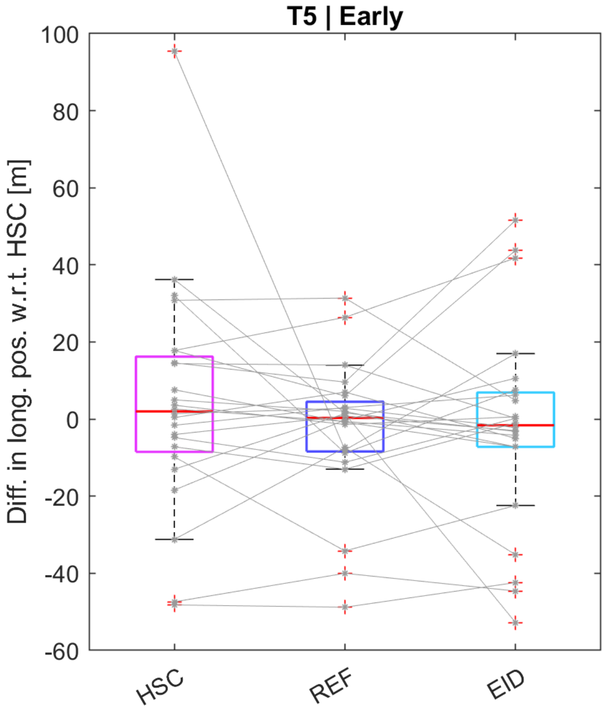




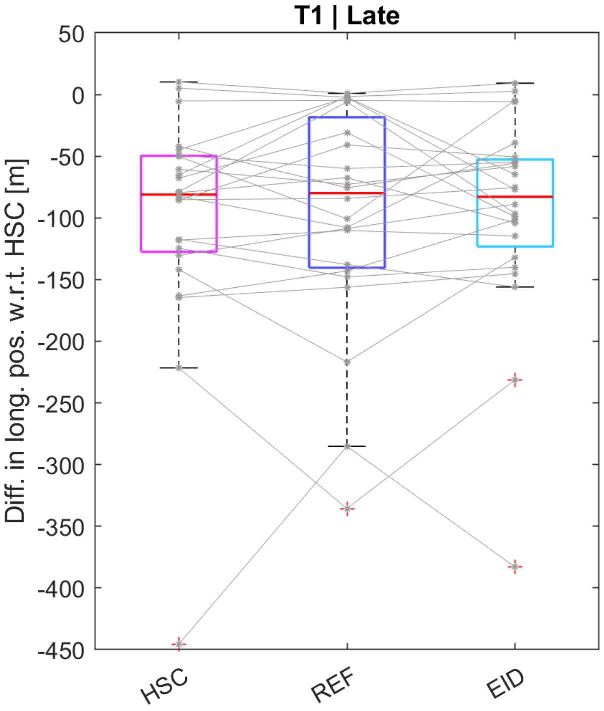


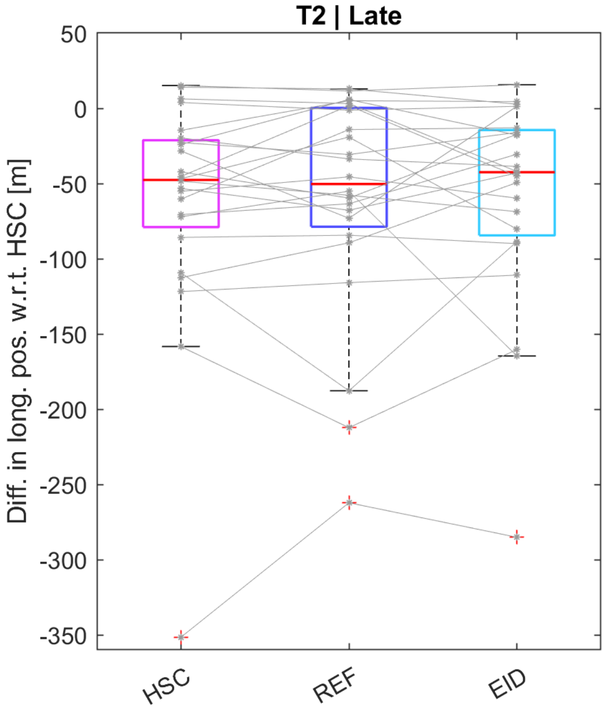


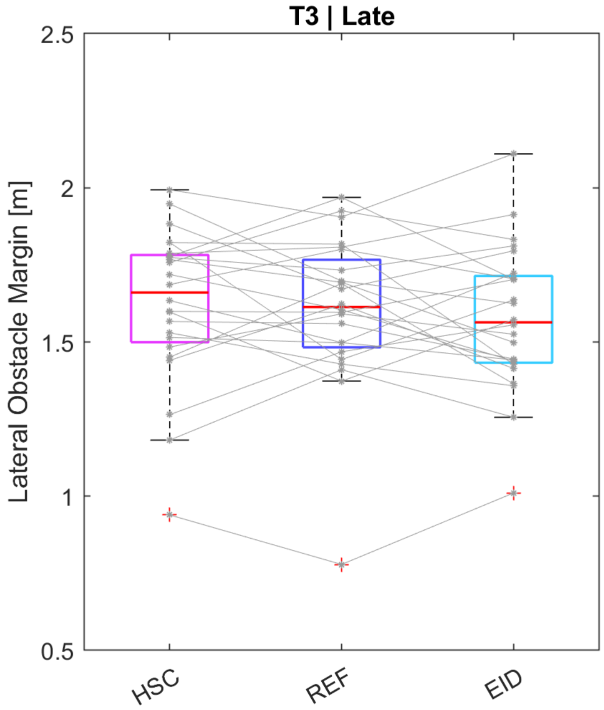


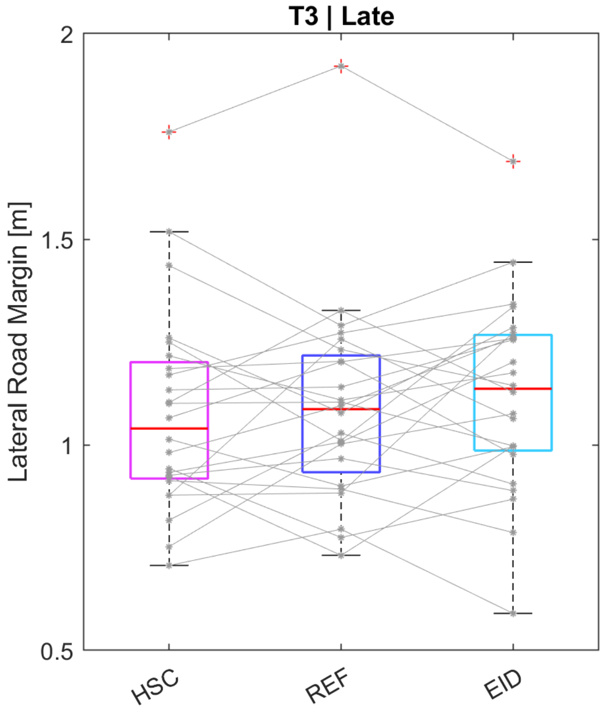


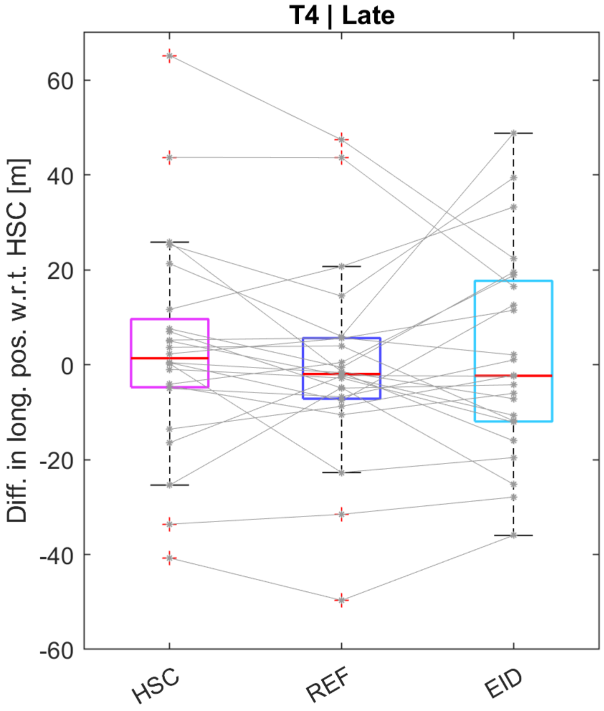
Late overtake

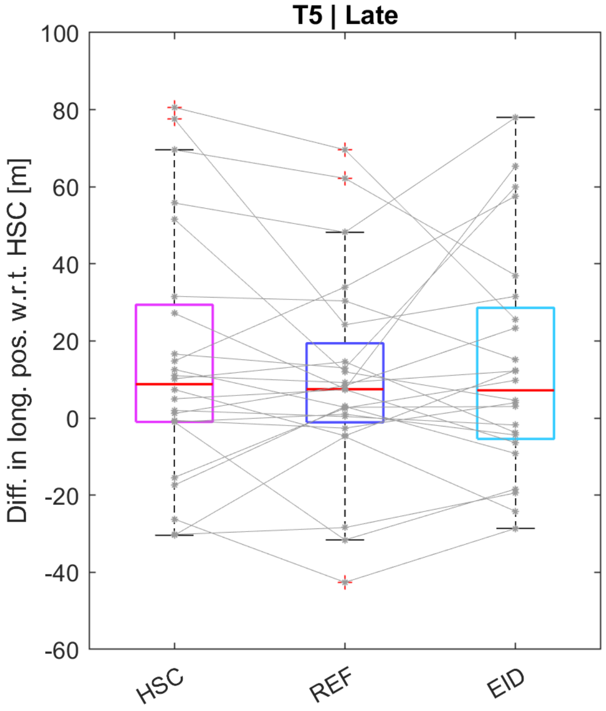





T3 | Late

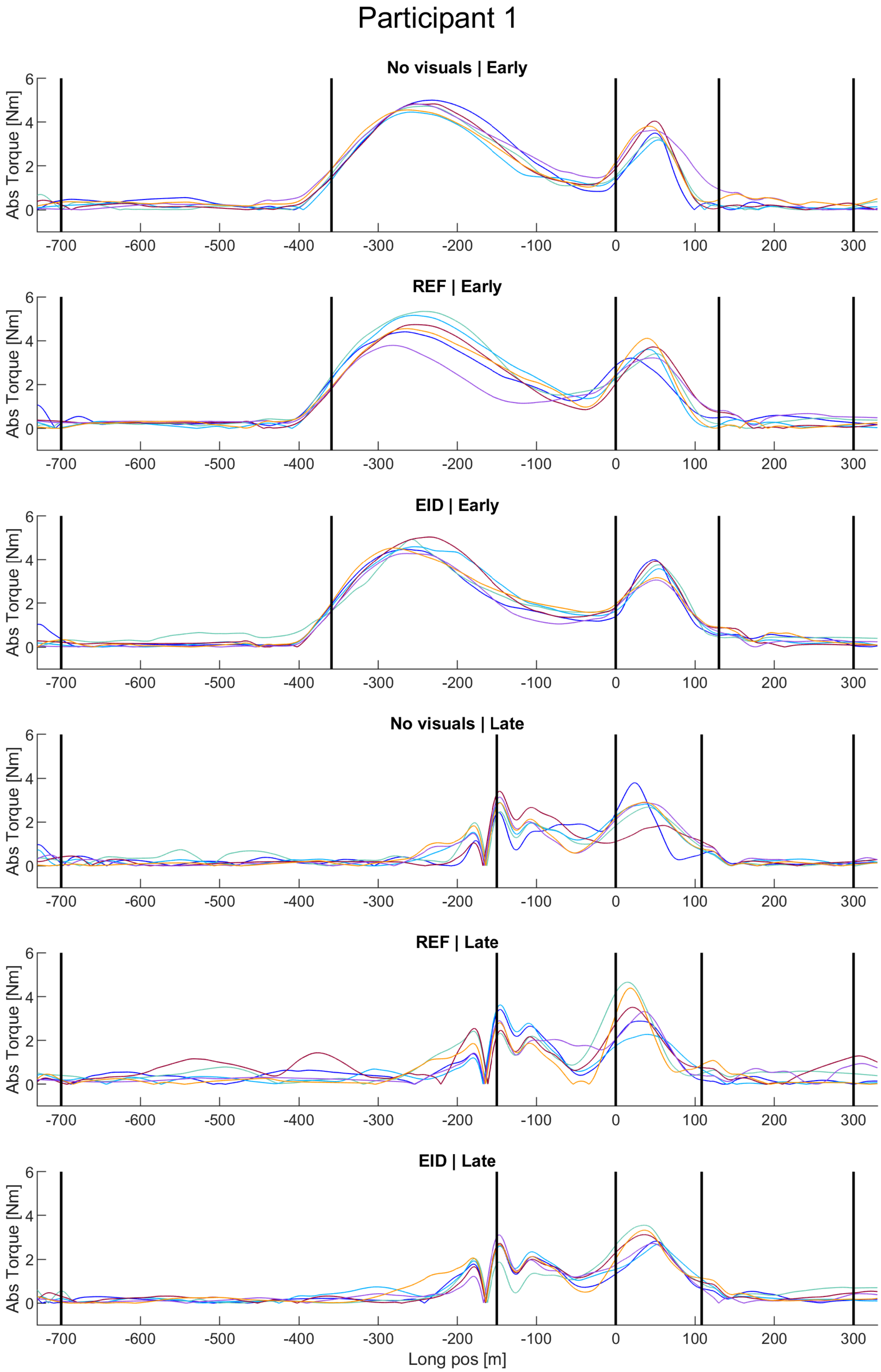

T3 | Late


T4 | Late

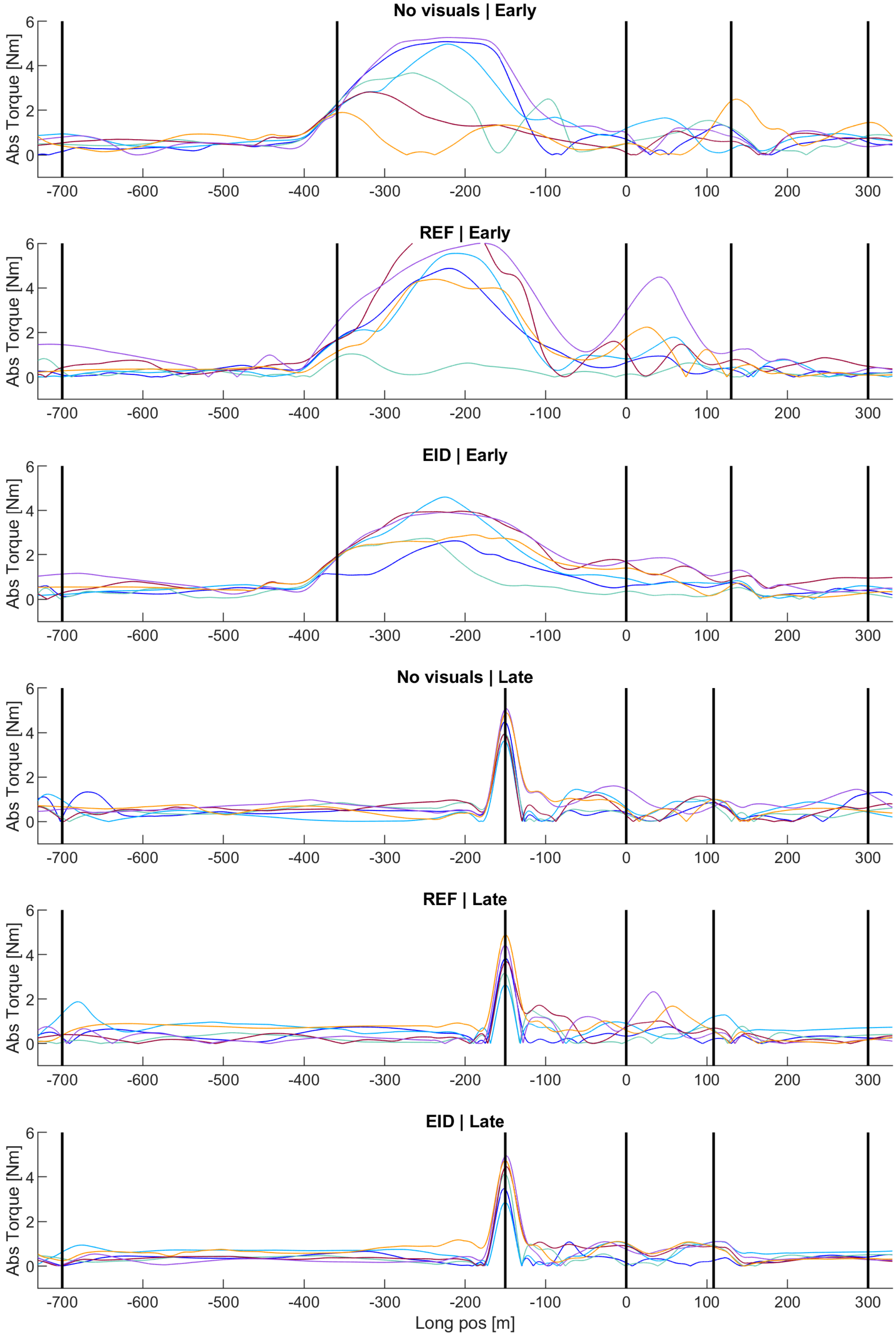

T5 | Late

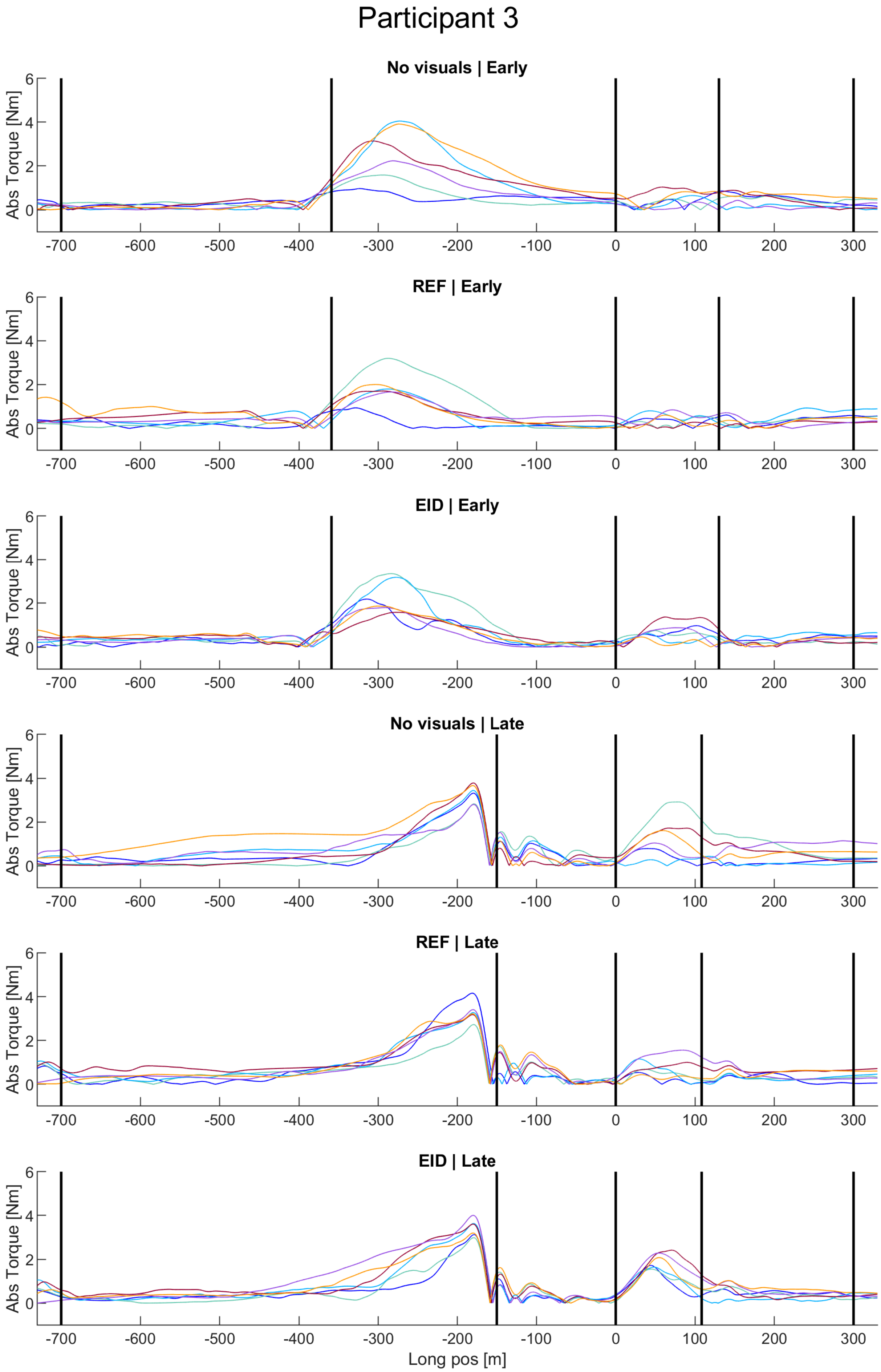
F

HSC compliance

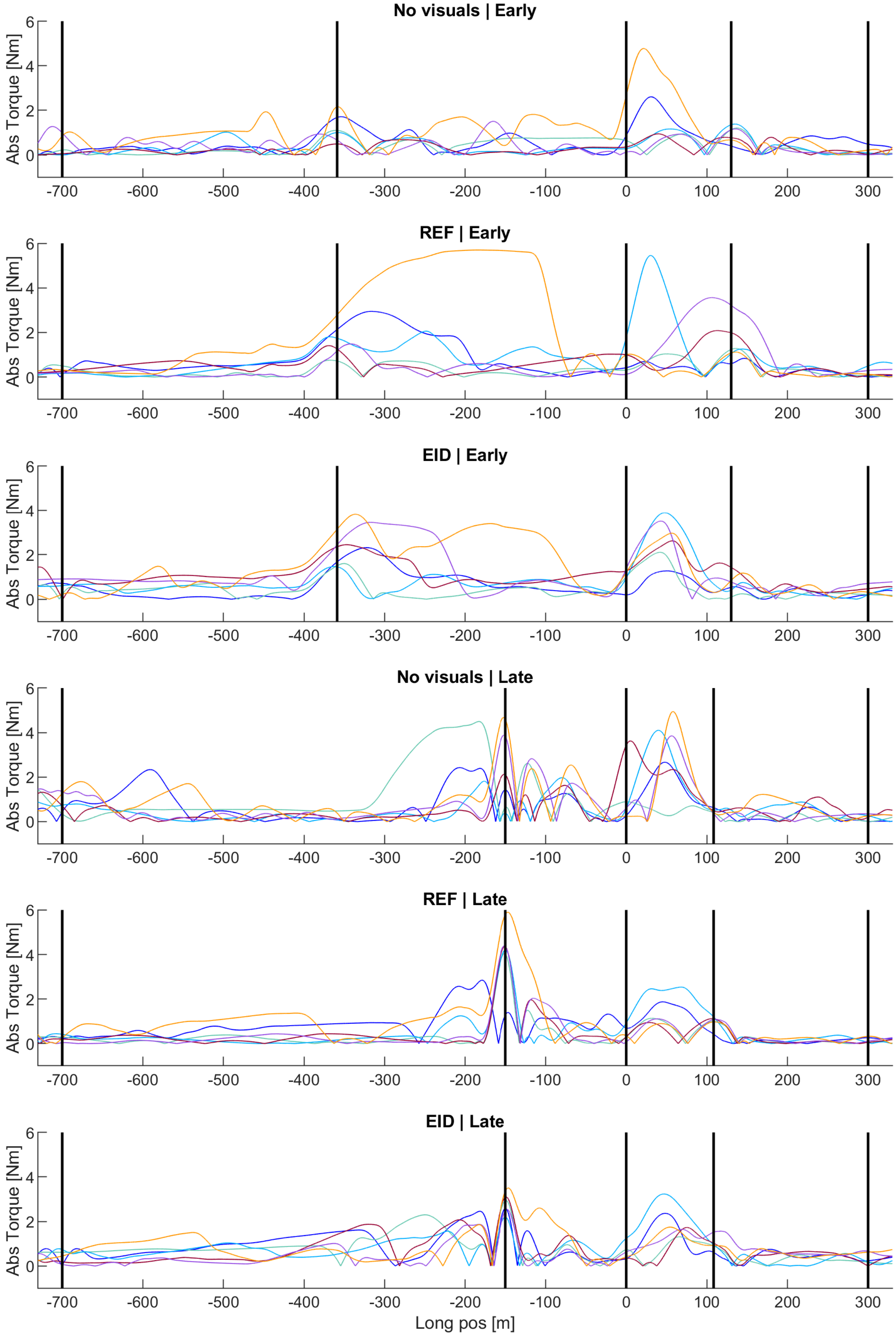

Participant 1
No visuals | Early
REF | Early
EID | Early
No visuals | Late
REF | Late
EID | Late
Abs Torque [Nm]
0
2
4
6
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]

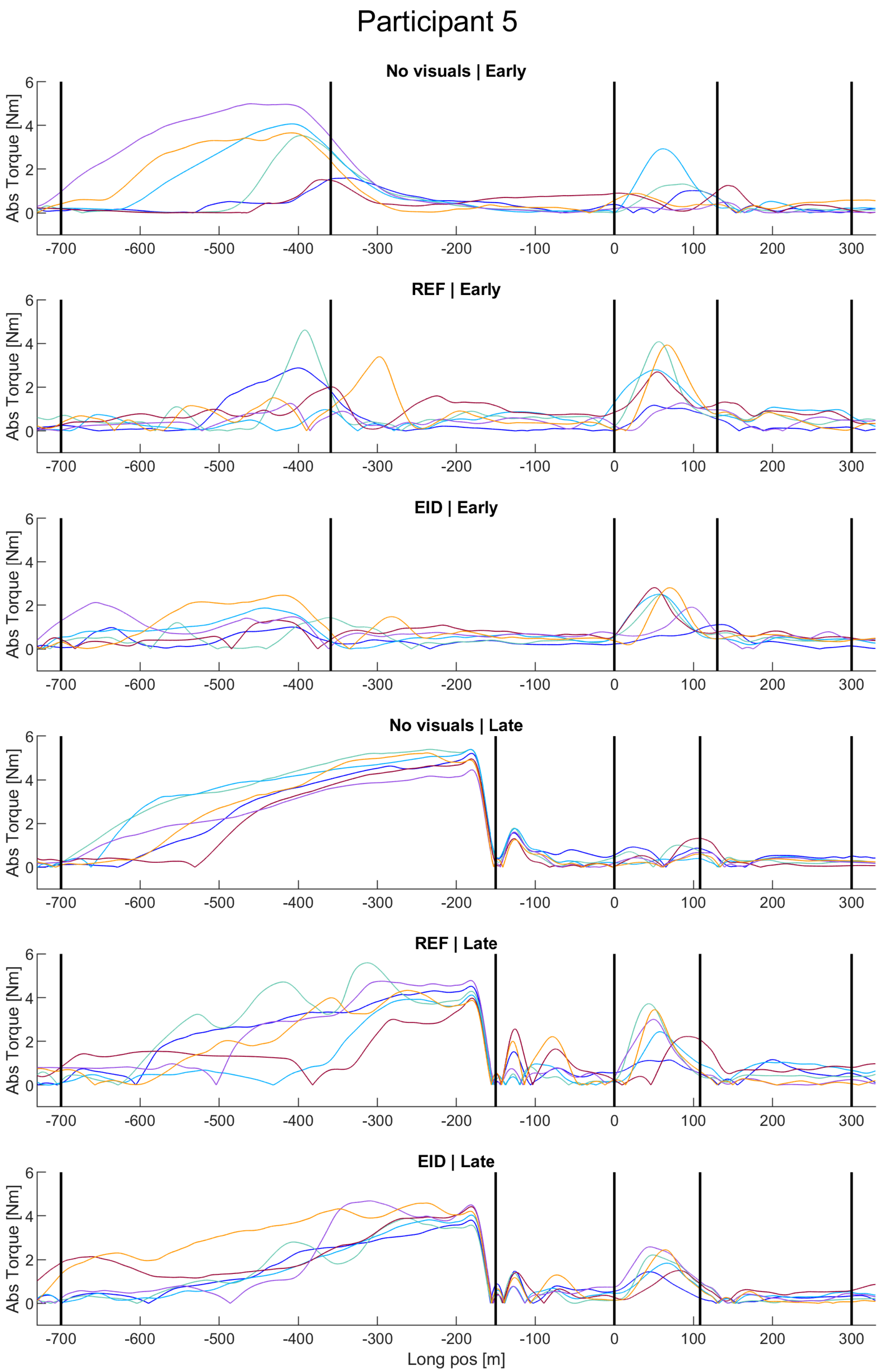
Participant 2

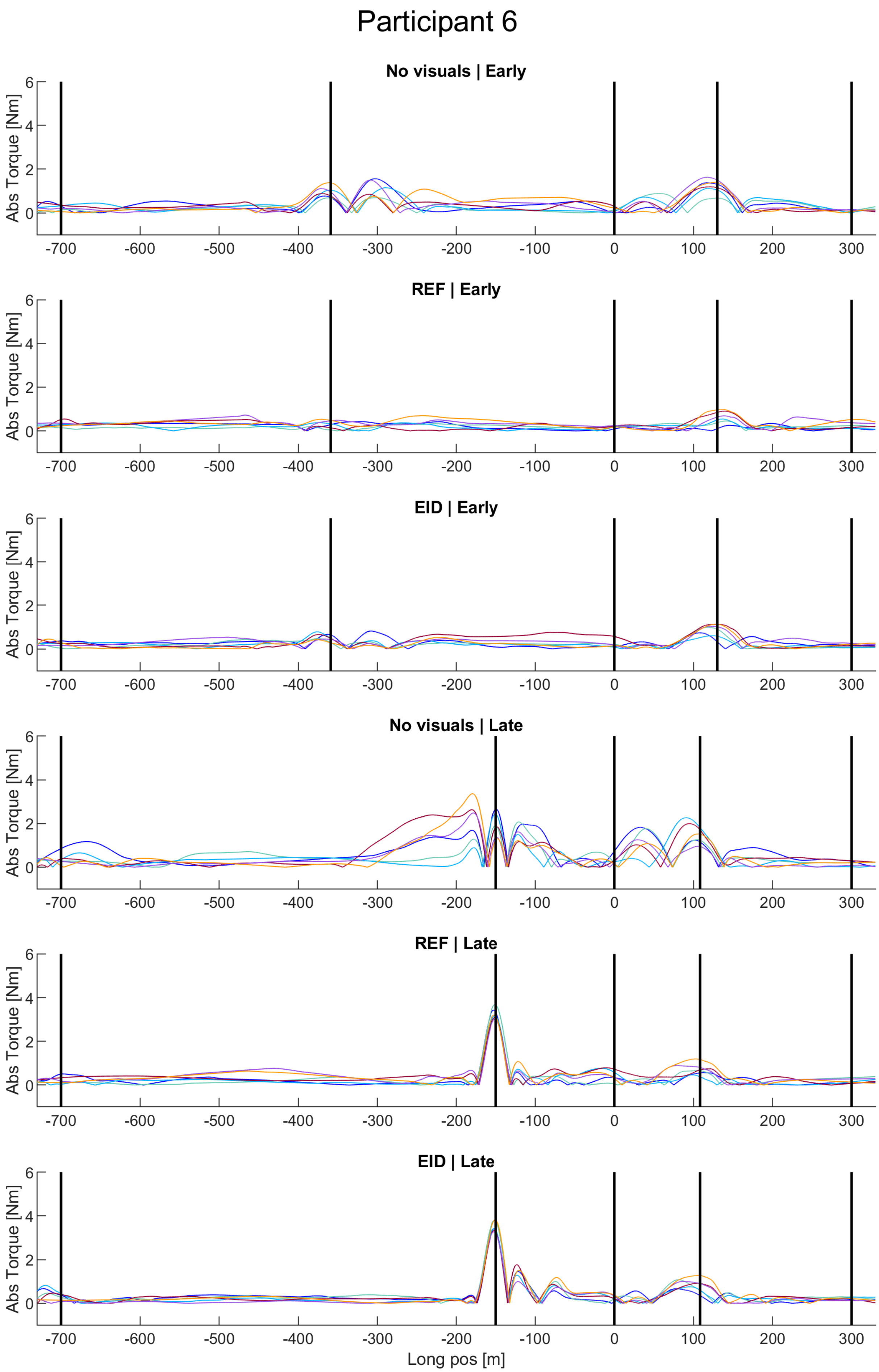



Participant 3
No visuals | Early
REF | Early
EID | Early
No visuals | Late
REF | Late
EID | Late
Abs Torque [Nm]
0
2
4
6
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]

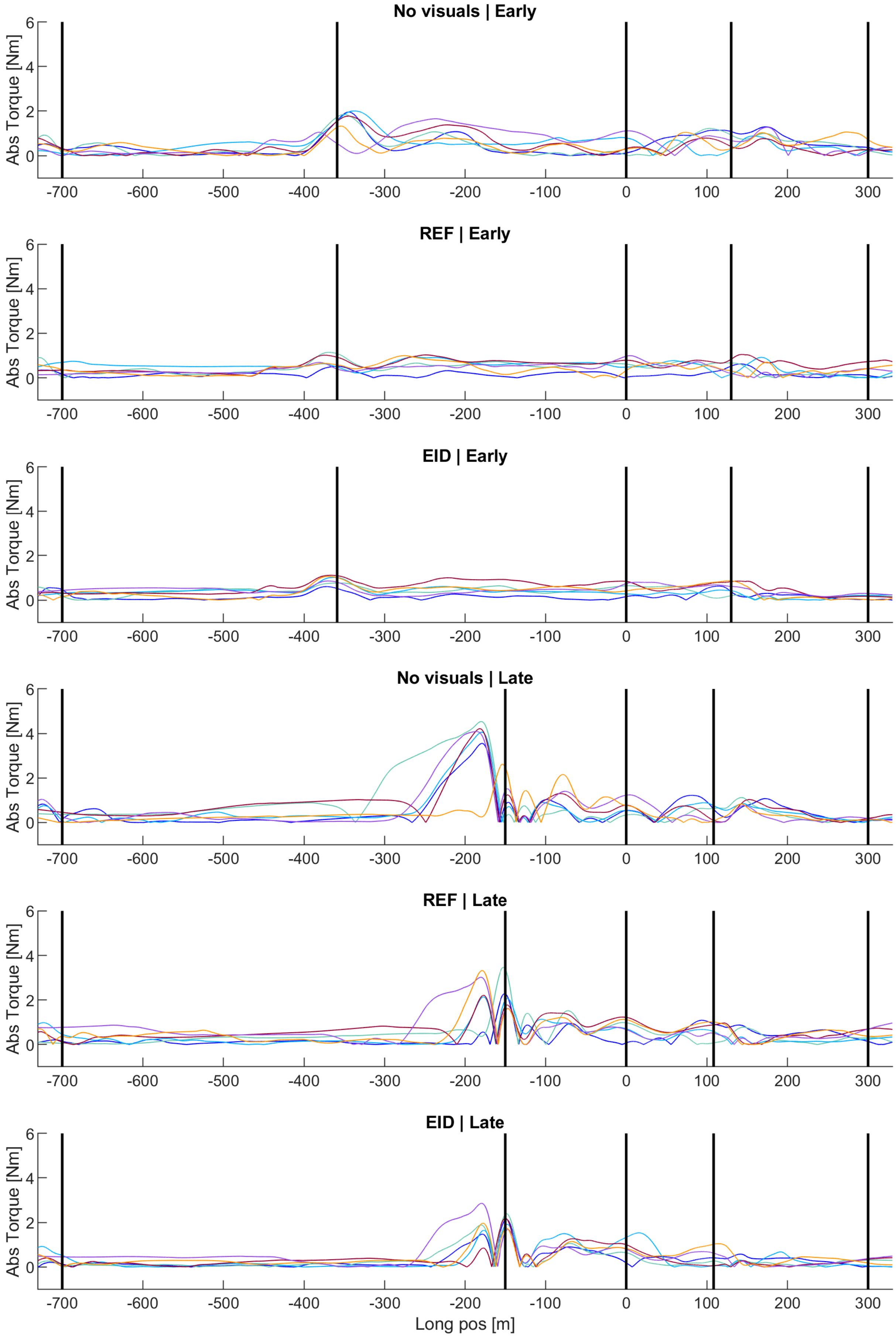
Participant 4



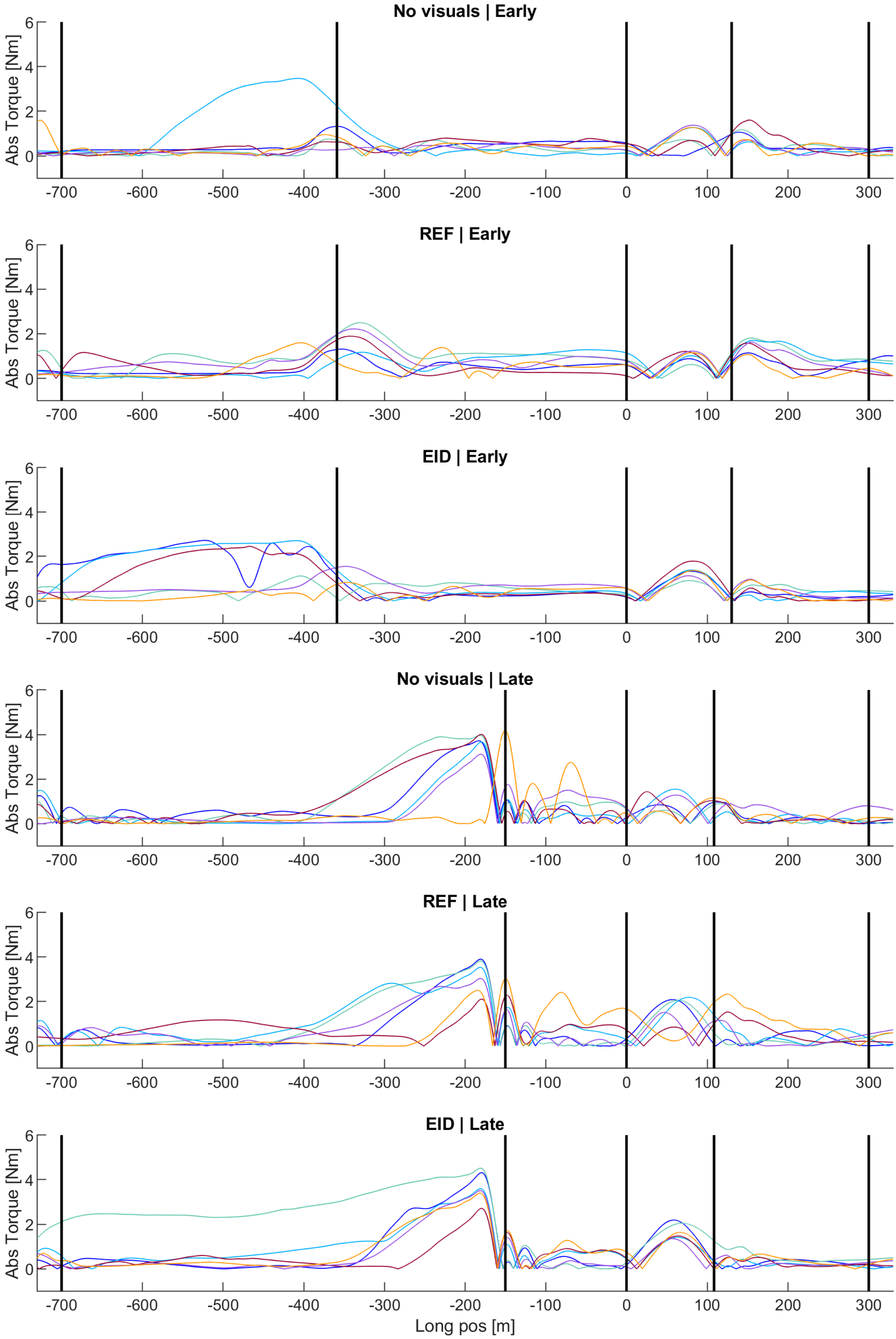

Participant 5
No visuals | Early
REF | Early
EID | Early
No visuals | Late
REF | Late
EID | Late
Abs Torque [Nm]
0
2
4
6
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]


Participant 6
No visuals | Early
REF | Early
EID | Early
No visuals | Late
REF | Late
EID | Late
Abs Torque [Nm]
0
2
4
6
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]

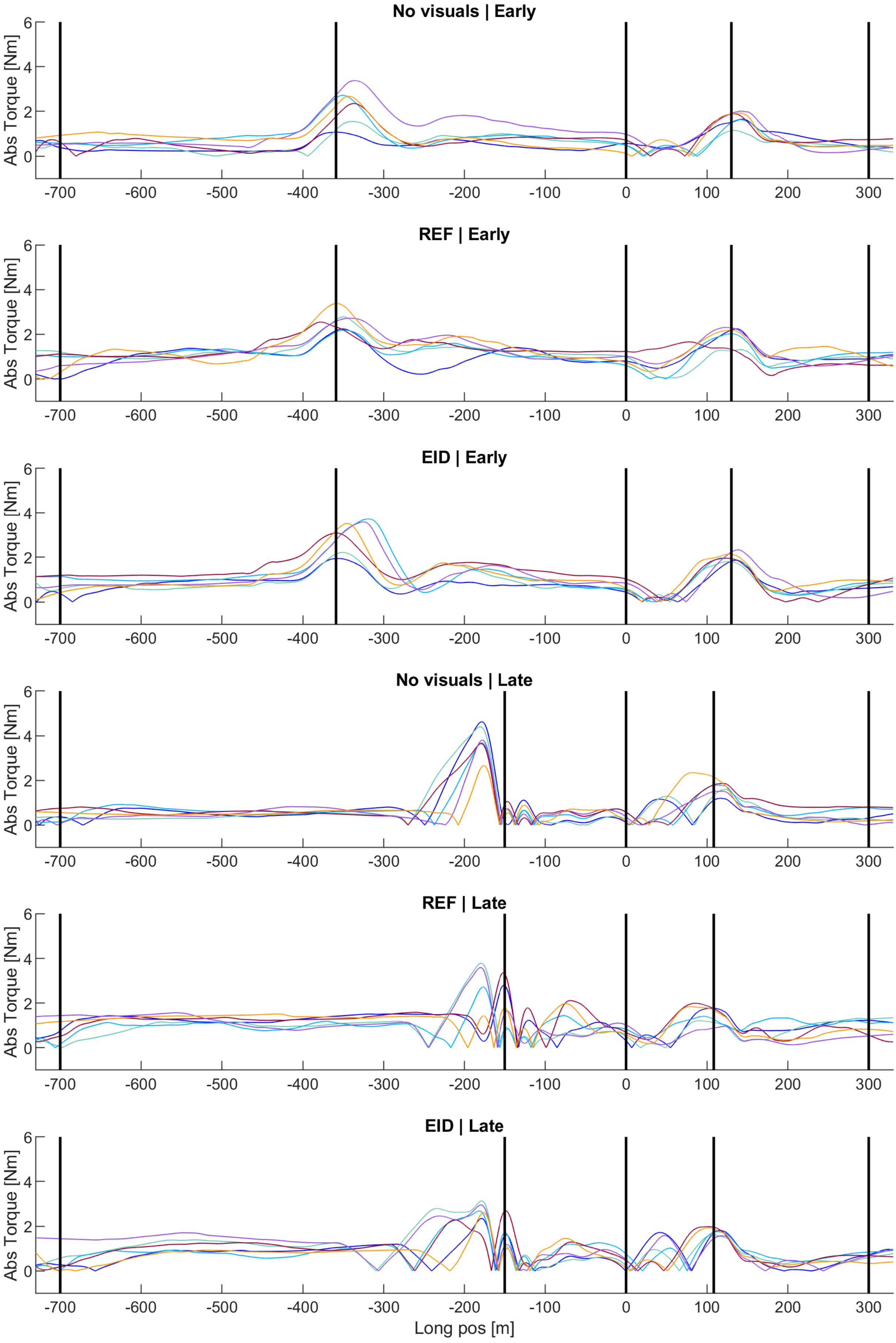
Participant 7



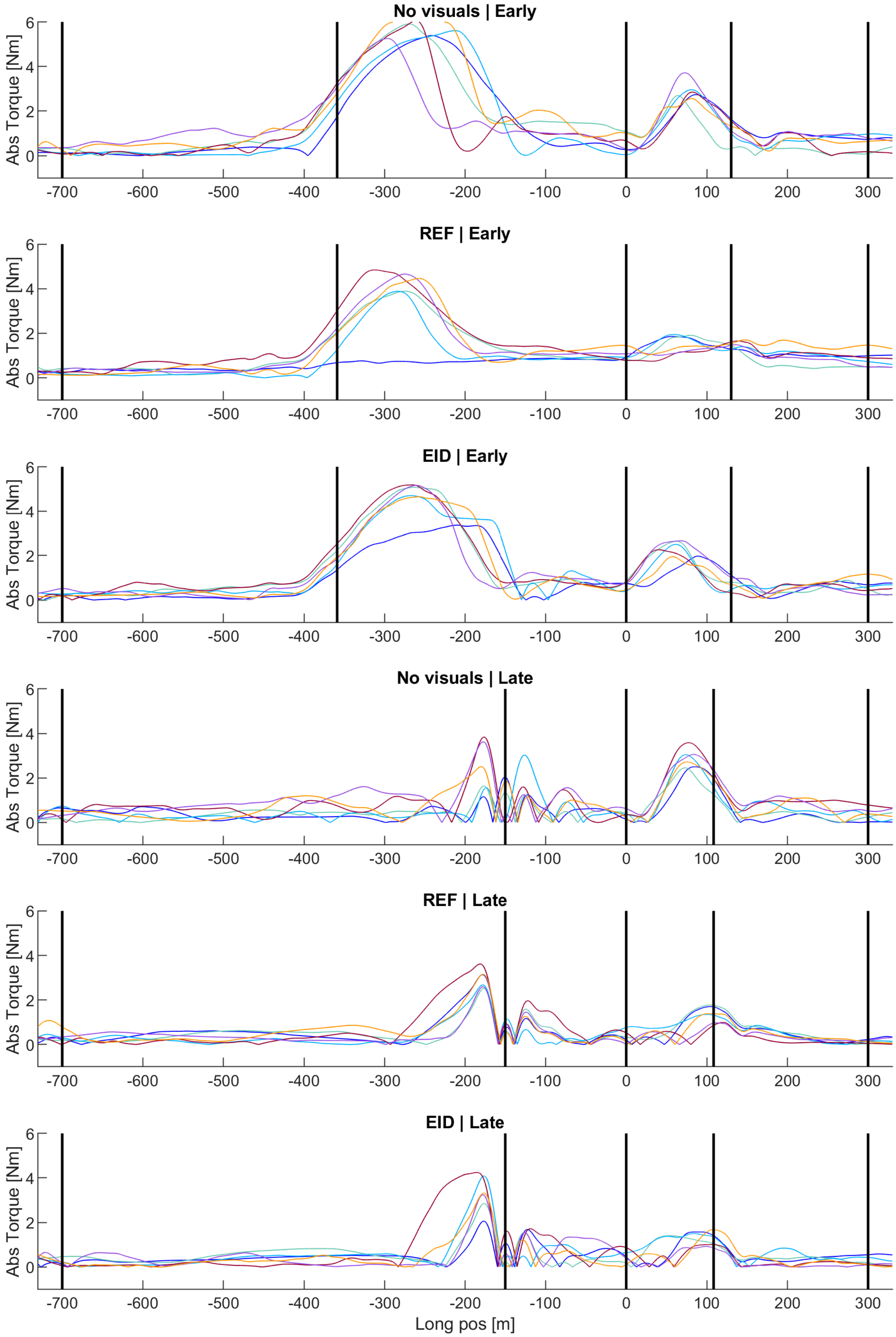
Participant 8



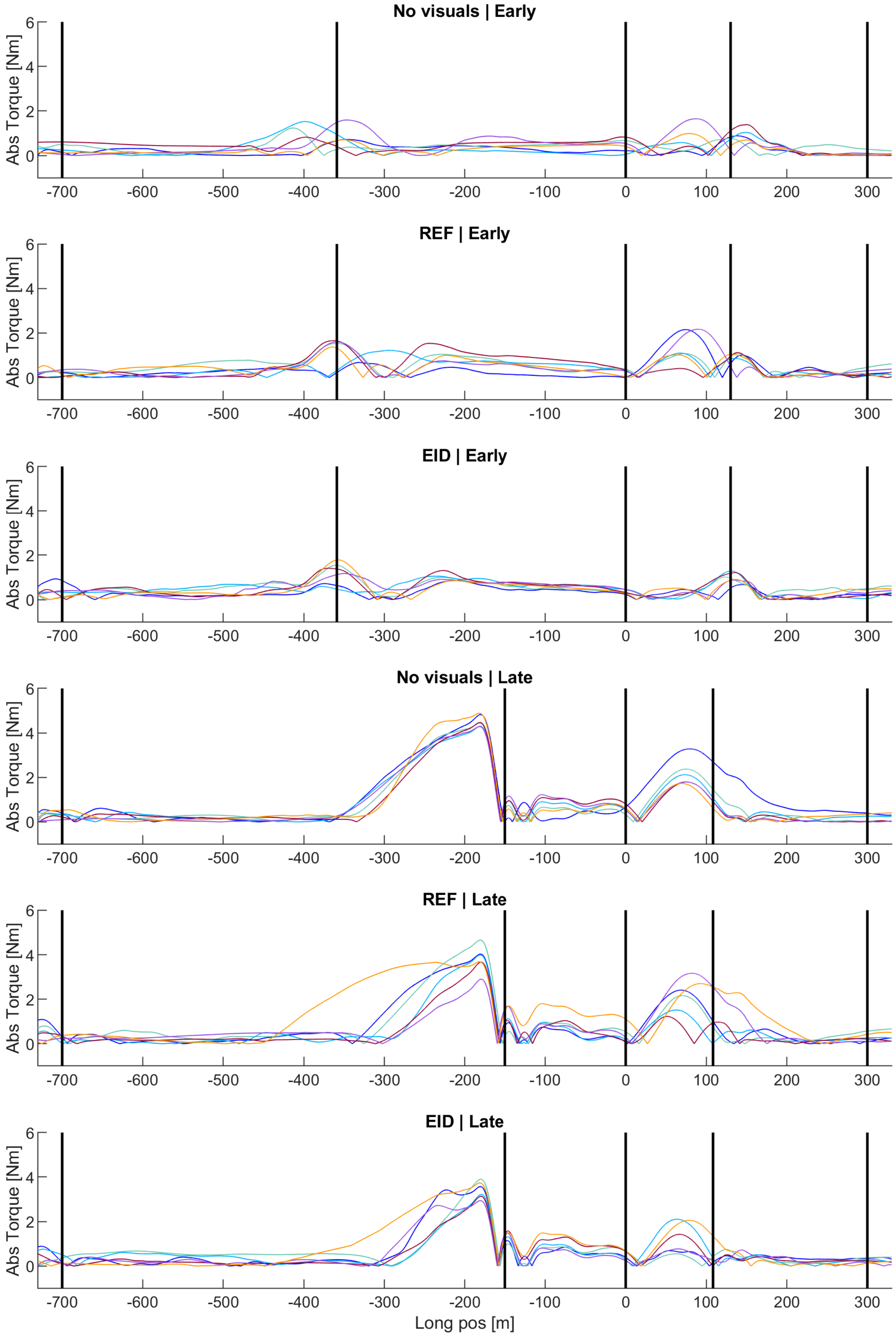
Participant 9



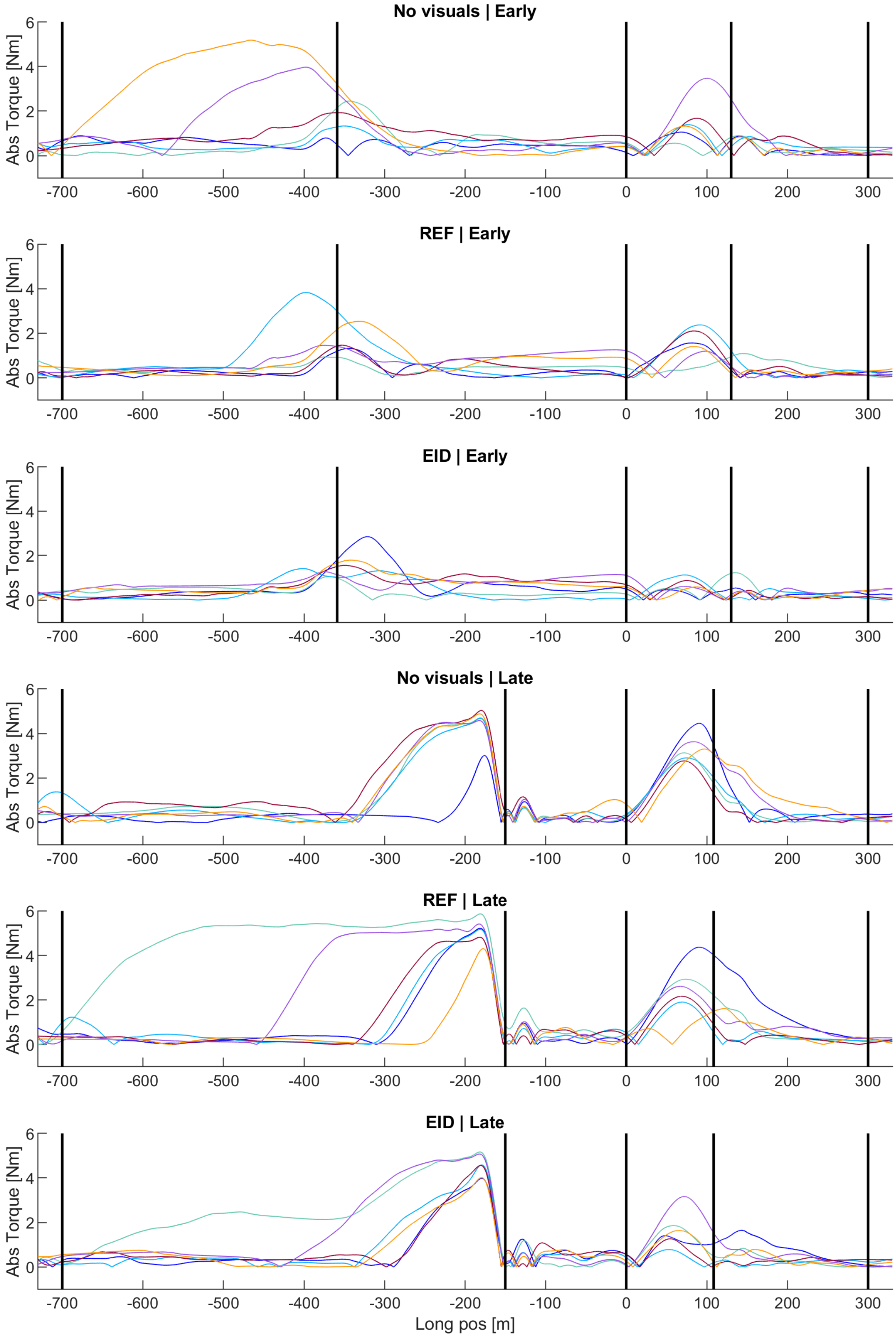
Participant 10



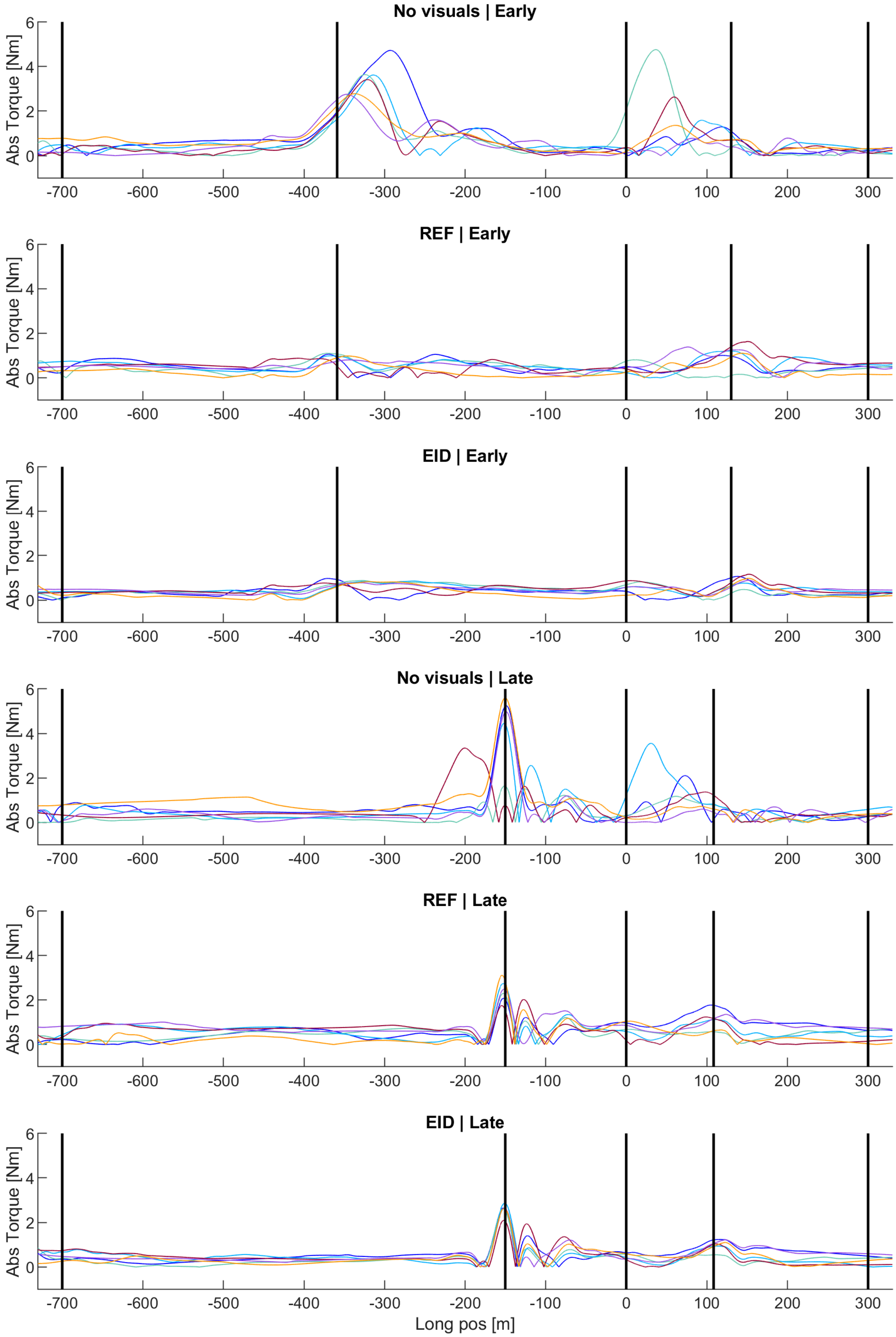
Participant 11



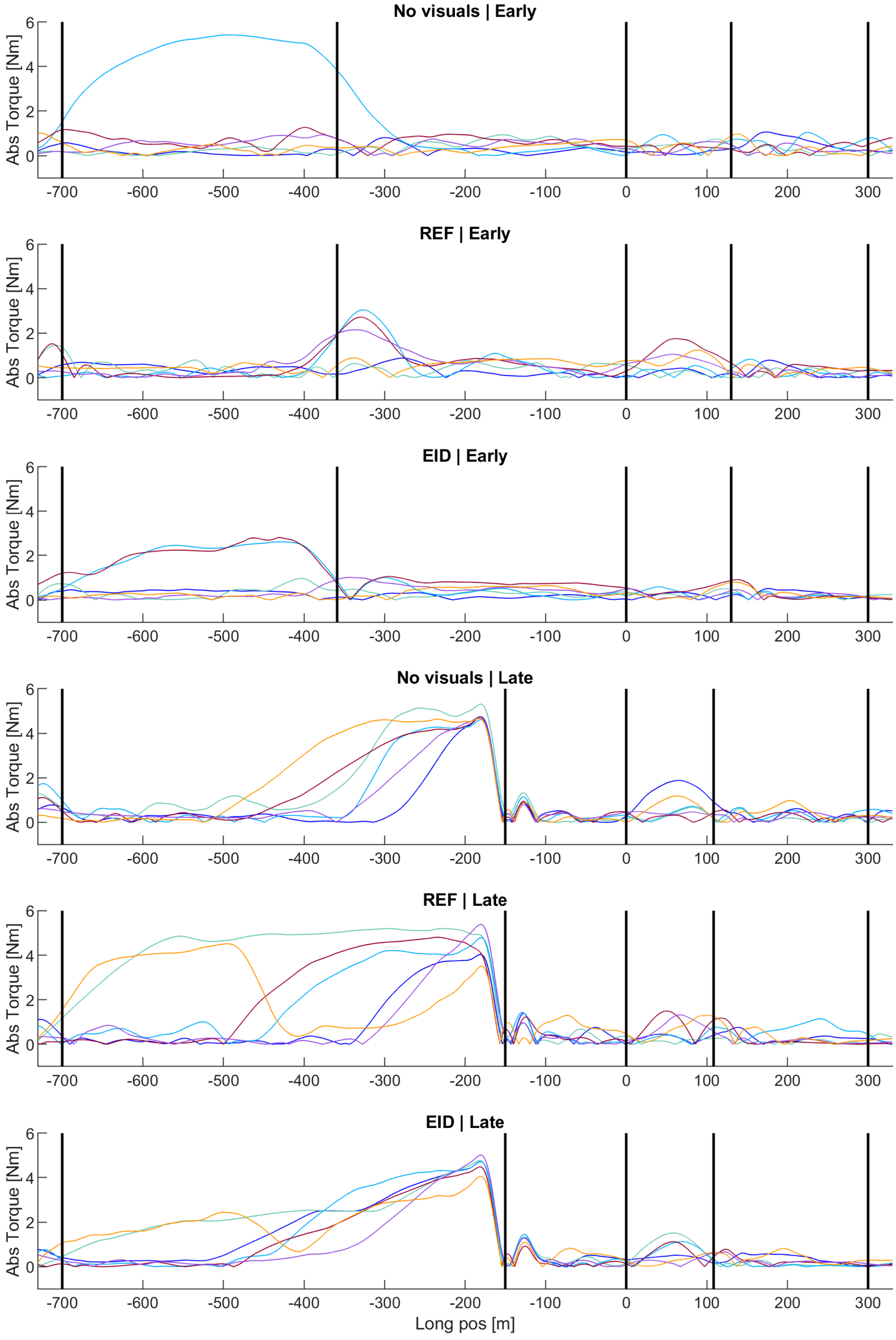
Participant 12



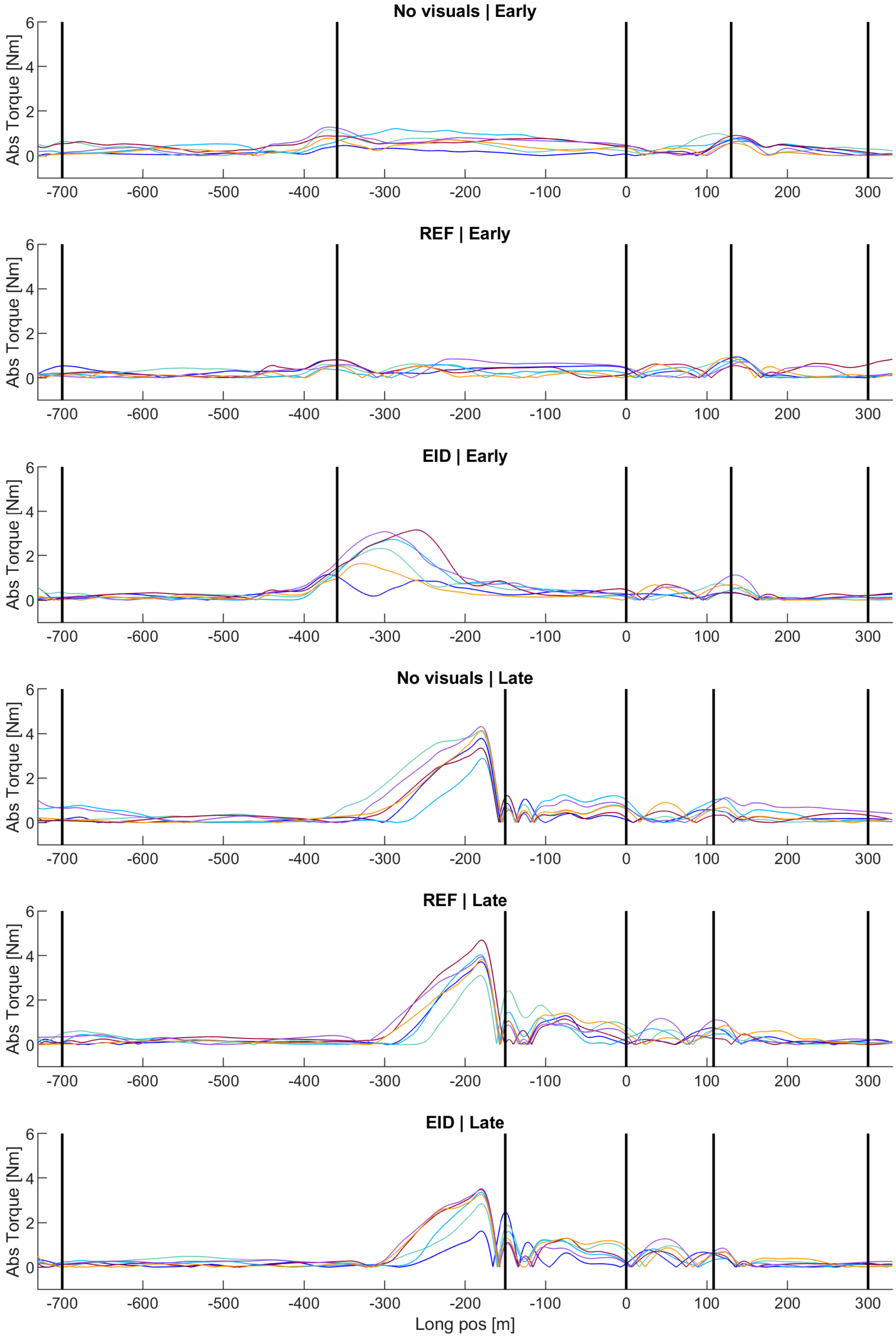
Participant 13



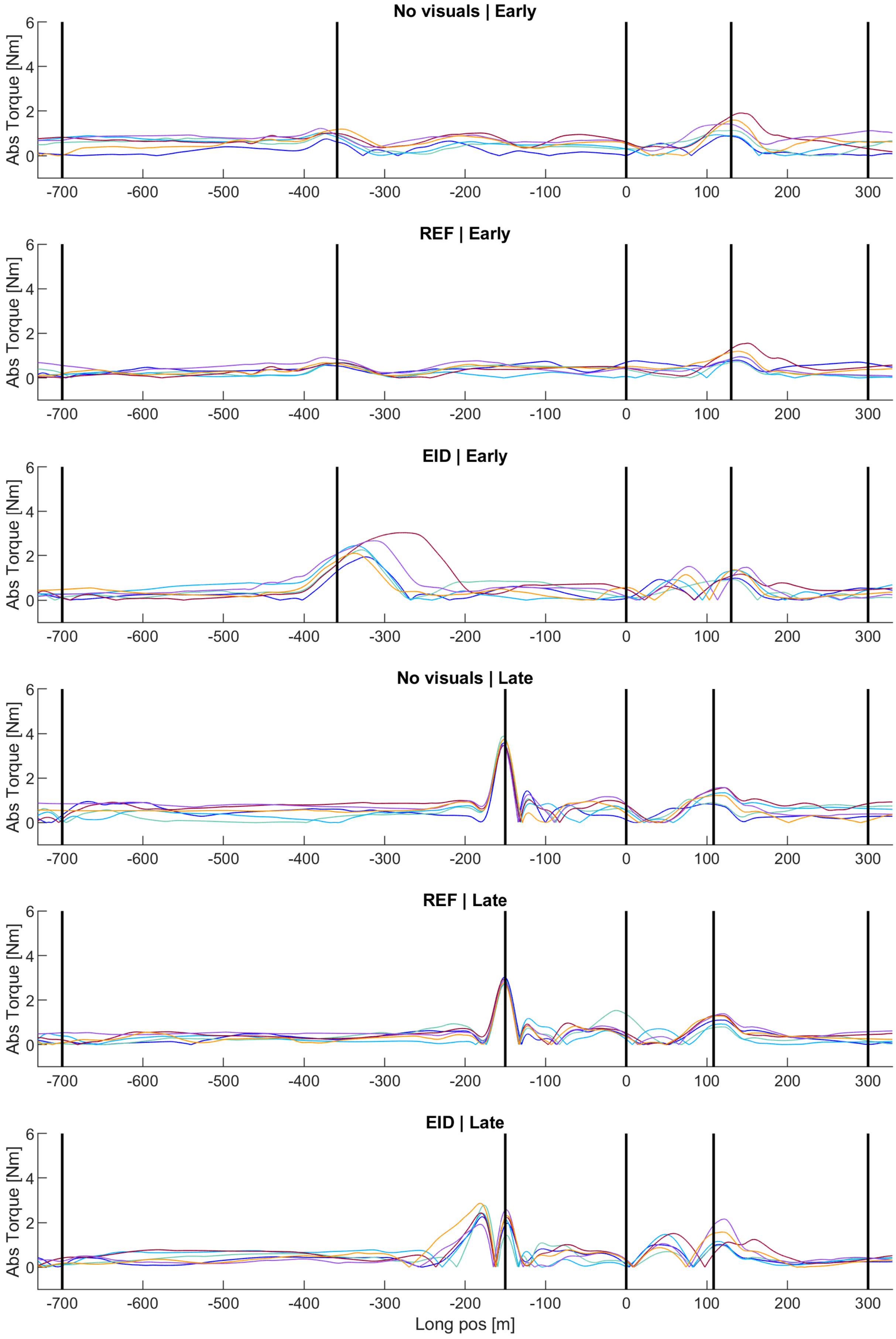
Participant 14

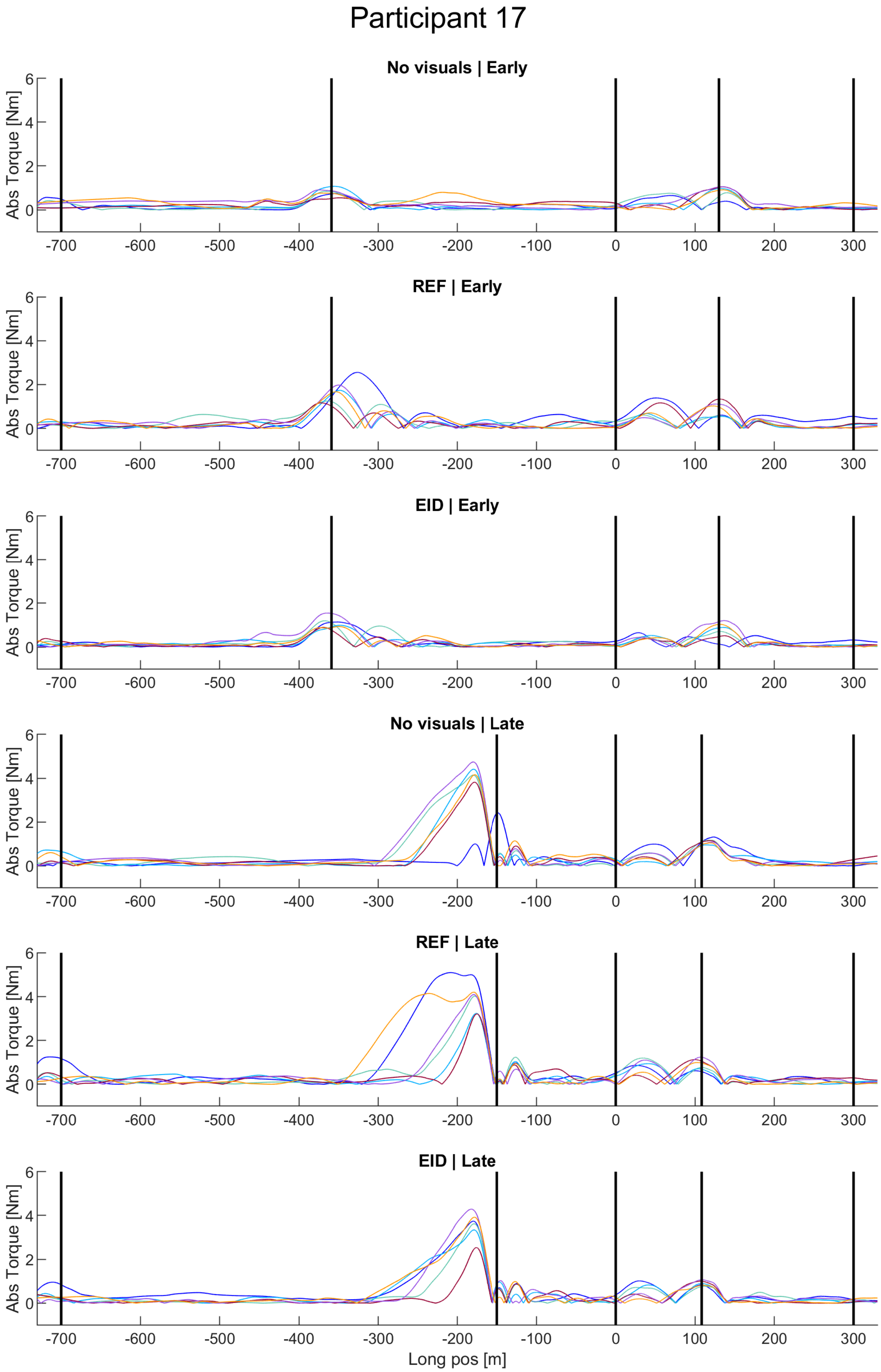


Participant 15

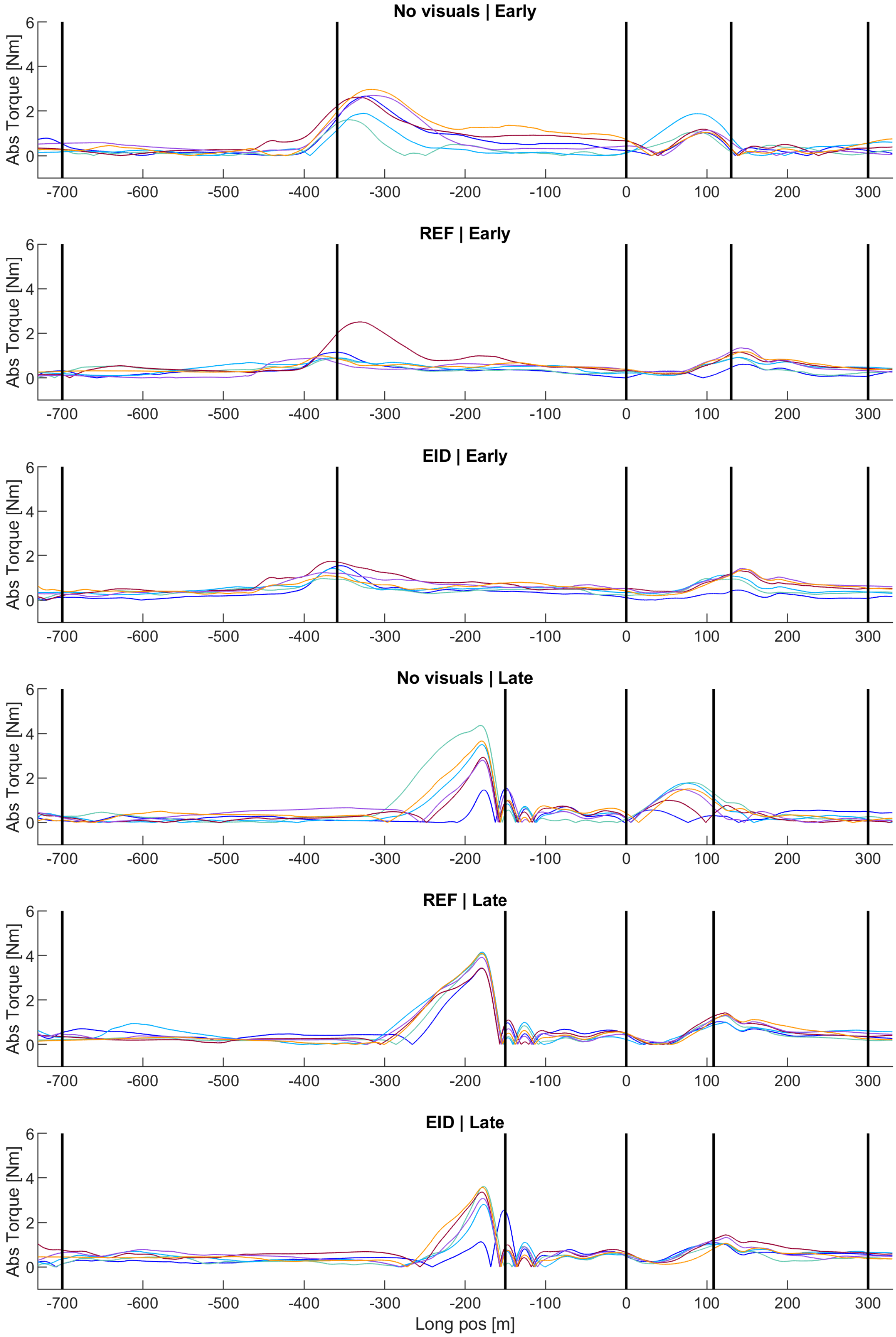


Participant 16

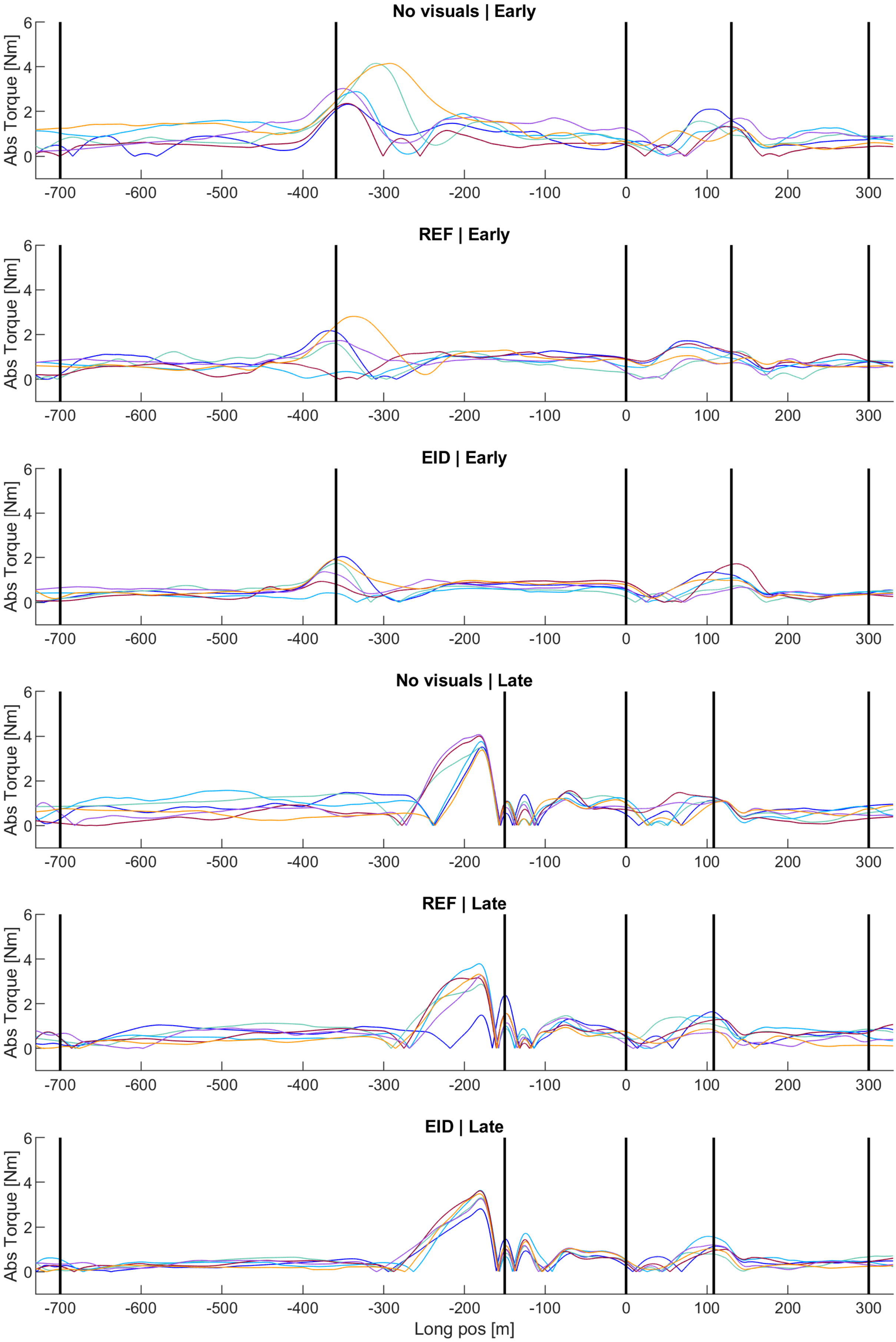



Participant 17
No visuals | Early
REF | Early
EID | Early
No visuals | Late
REF | Late
EID | Late
Abs Torque [Nm]
6
4
2
0
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]

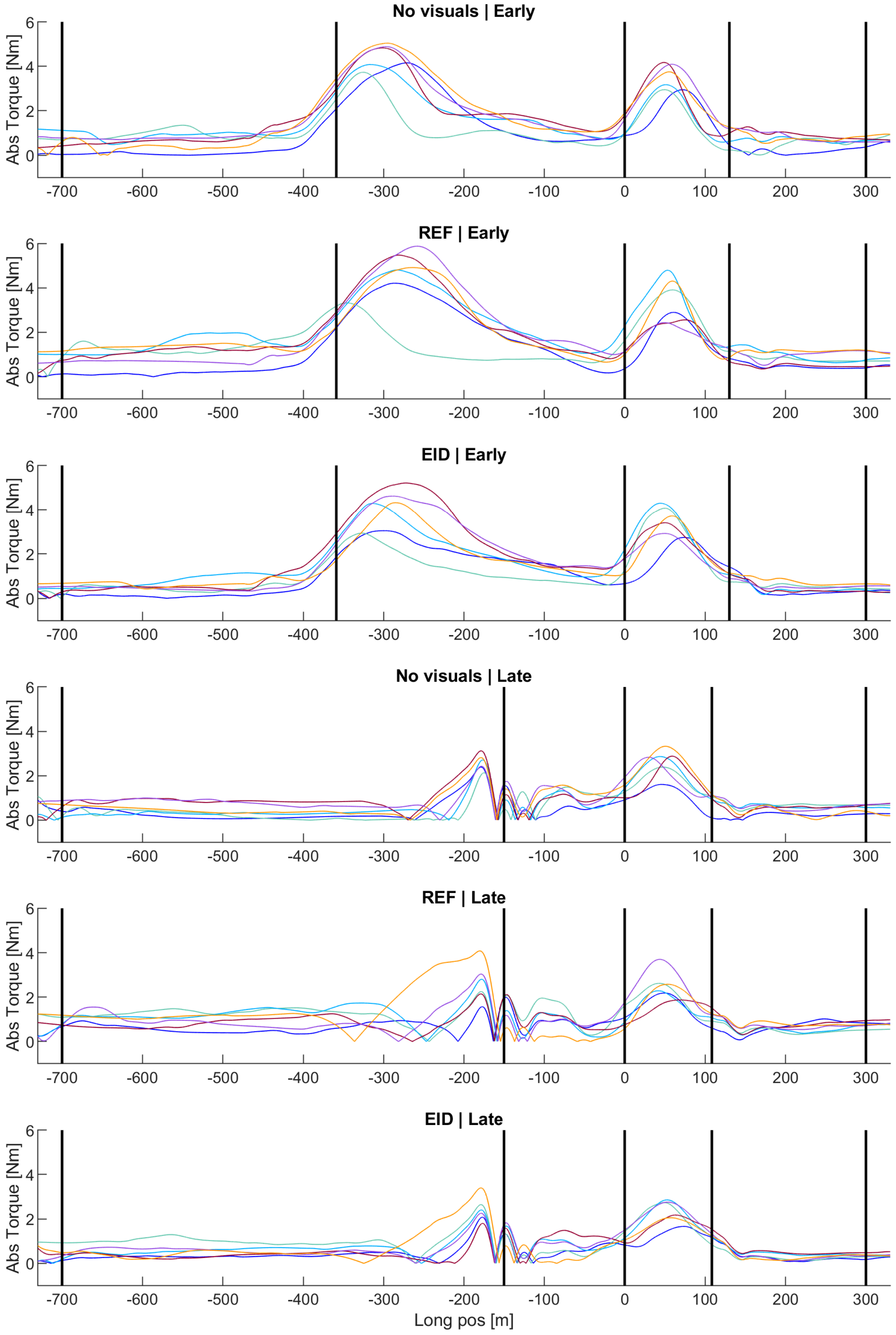
Participant 18



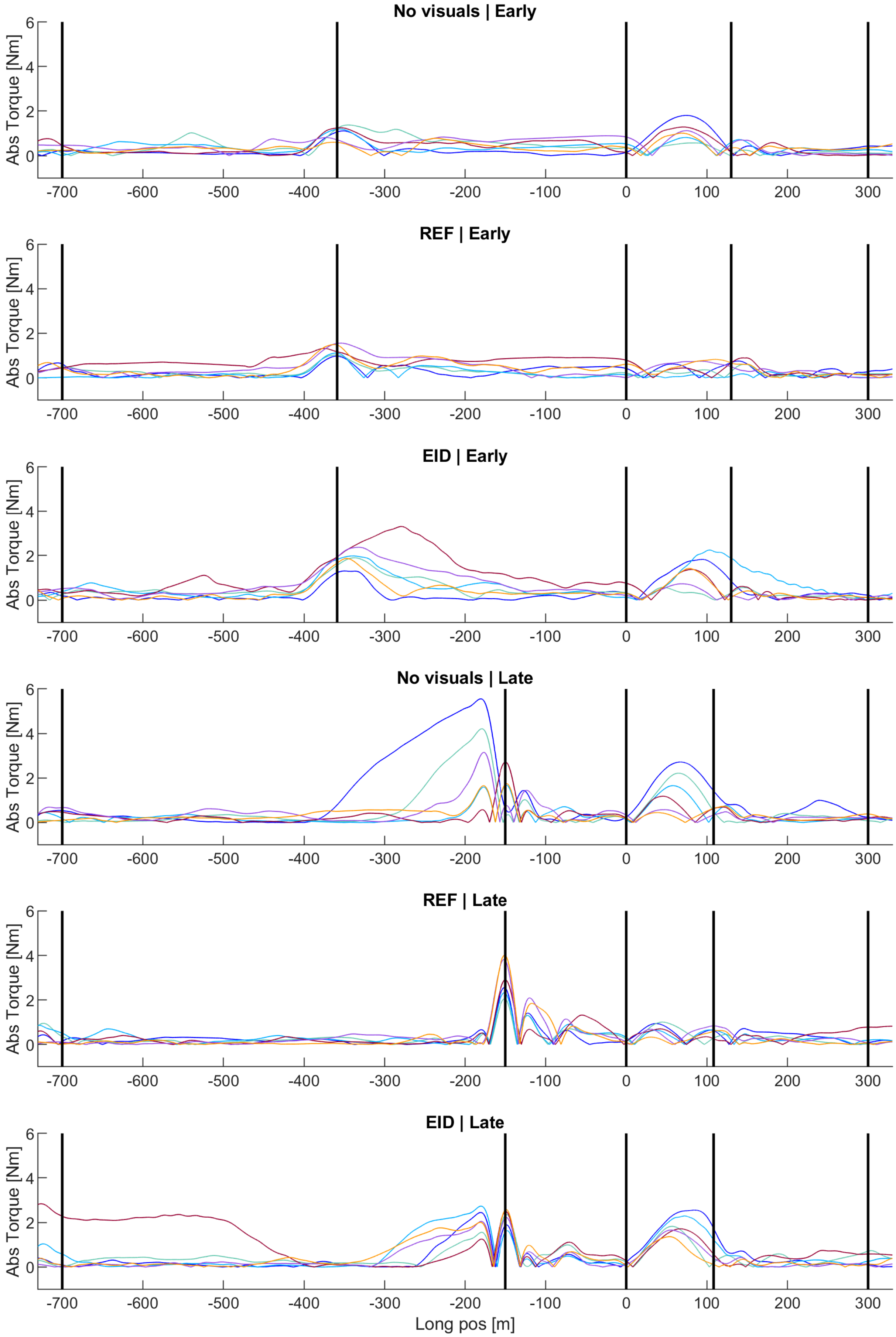
Participant 19



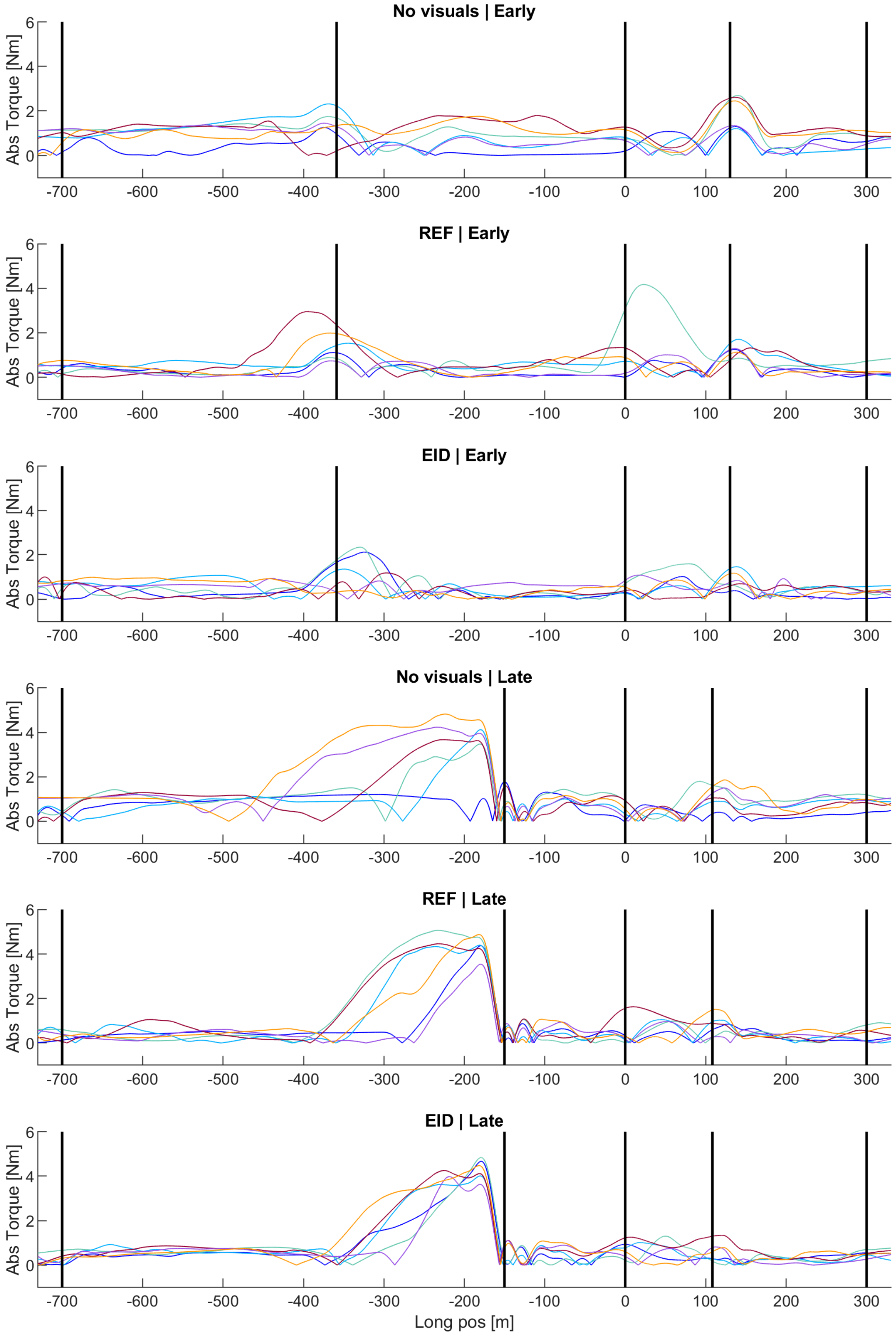
Participant 20



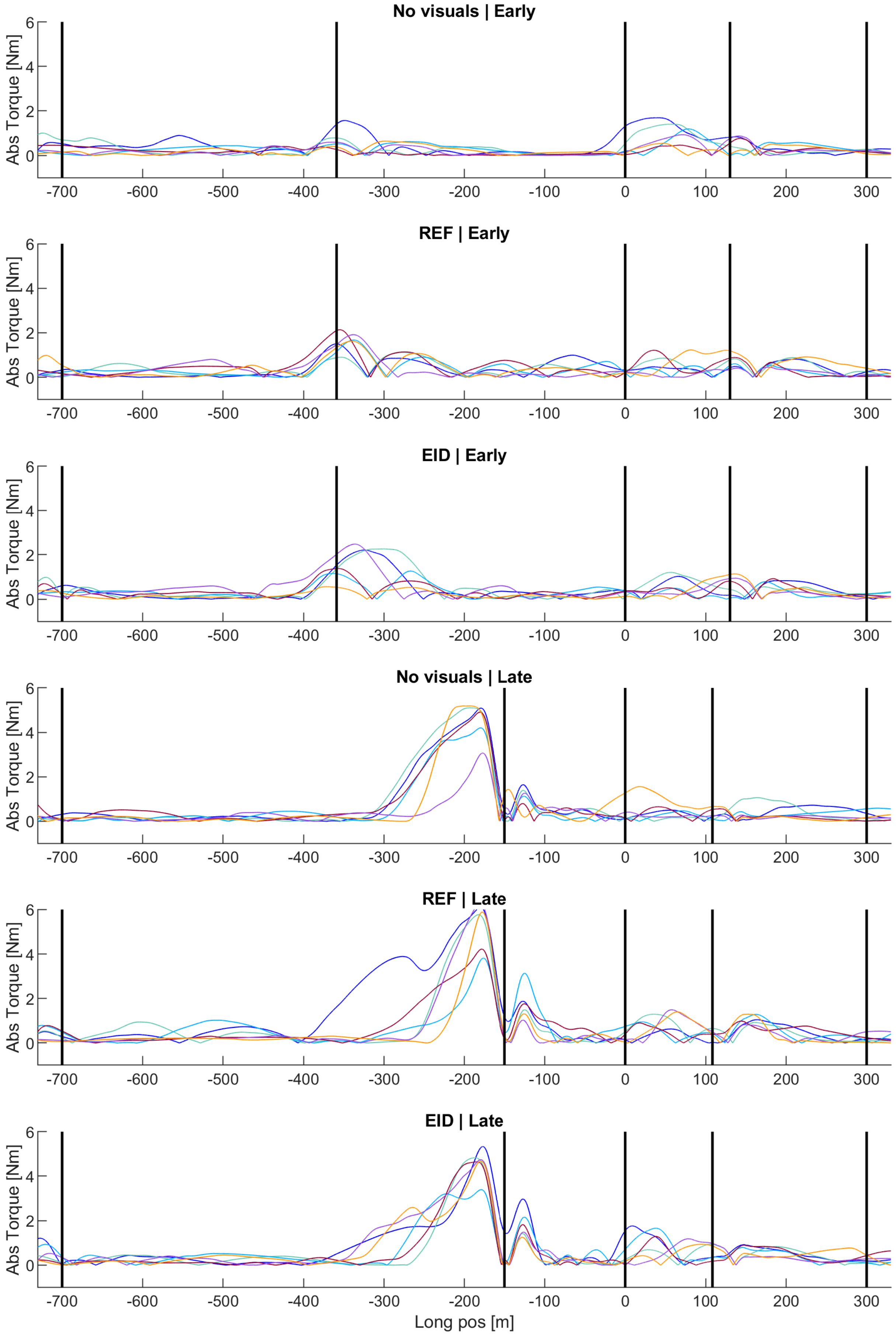
Participant 21

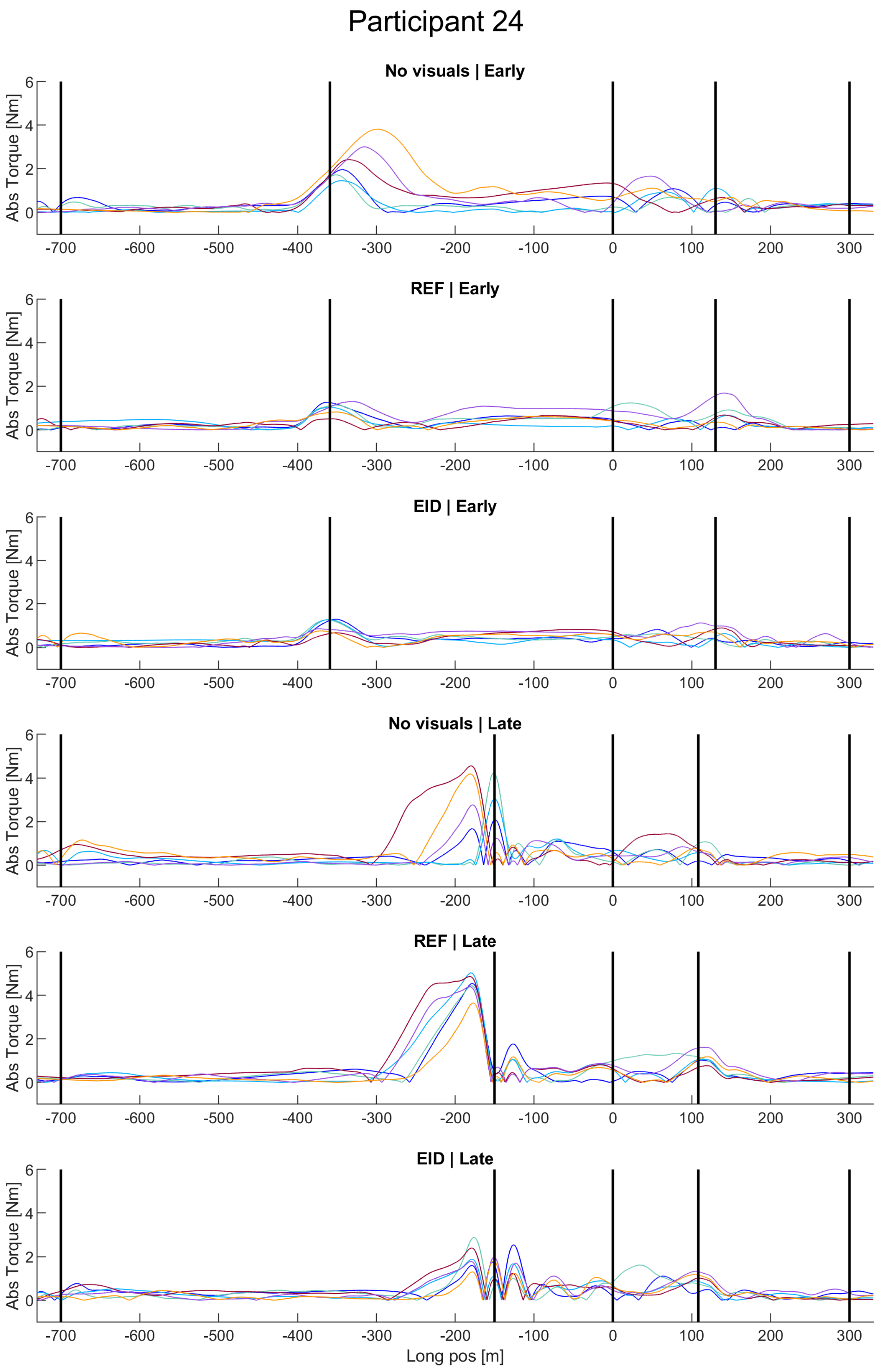


Participant 22



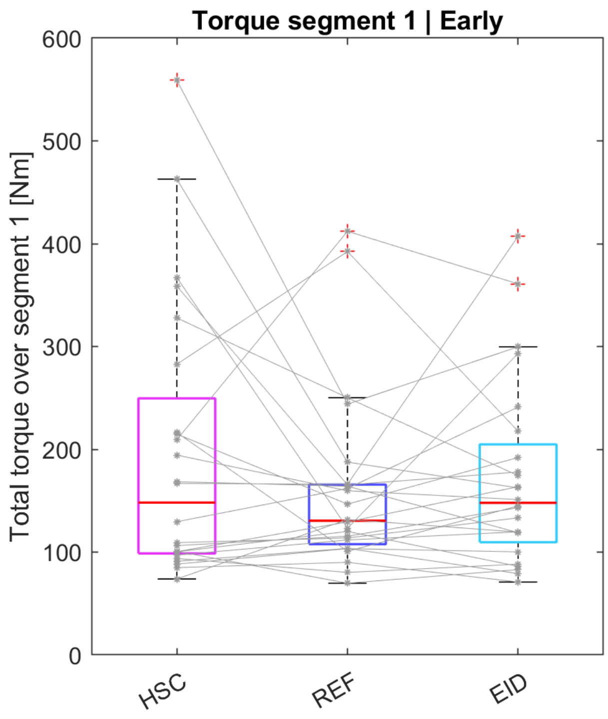
Participant 23

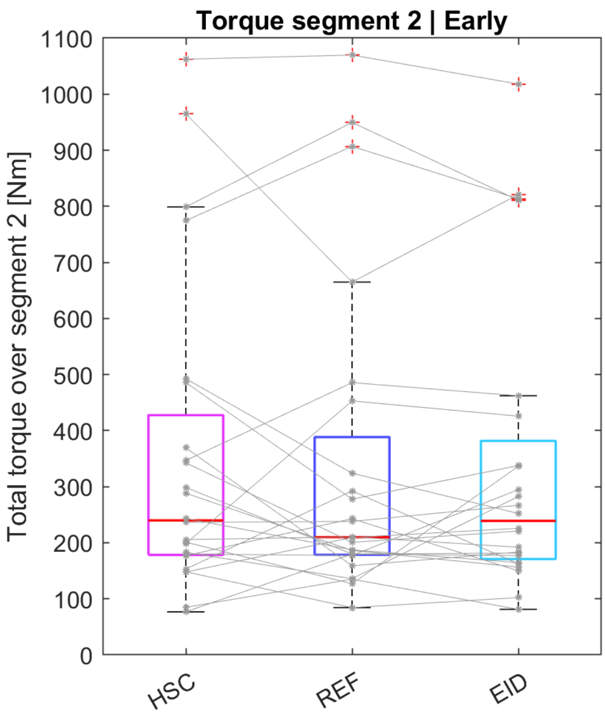


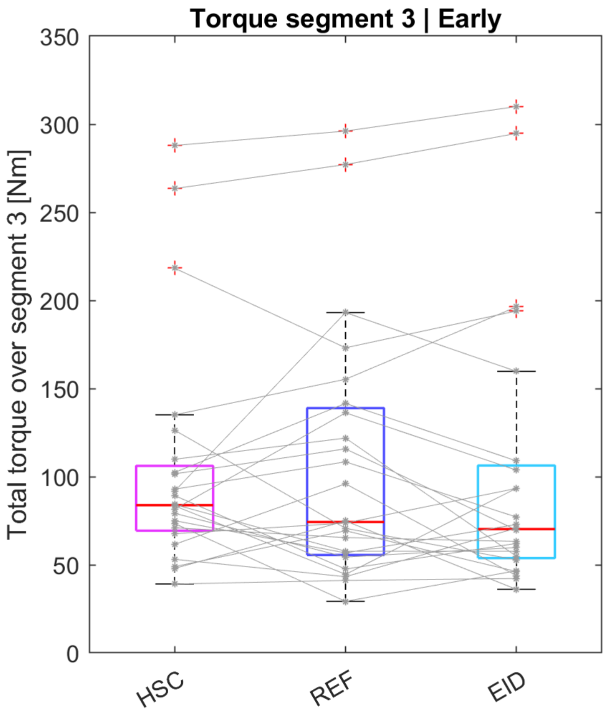

Participant 24
No visuals | Early
REF | Early
EID | Early
No visuals | Late
REF | Late
EID | Late
Abs Torque [Nm]
0
2
4
6
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
Long pos [m]

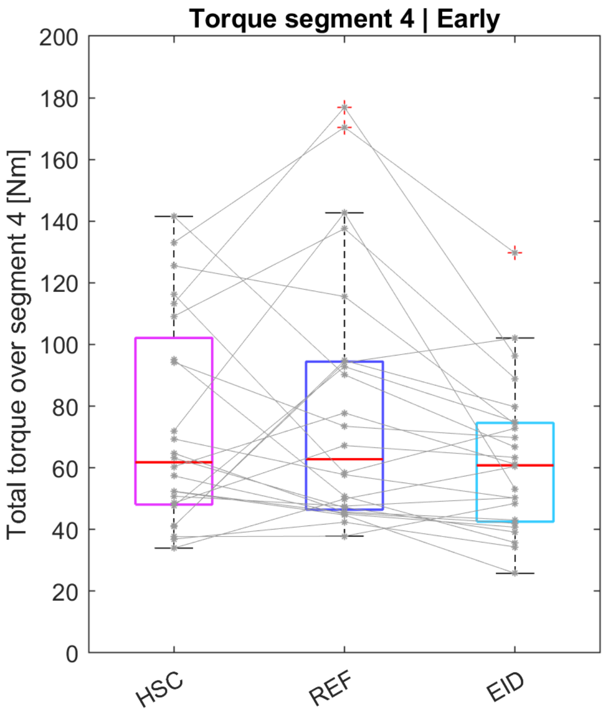
HSC Compliance

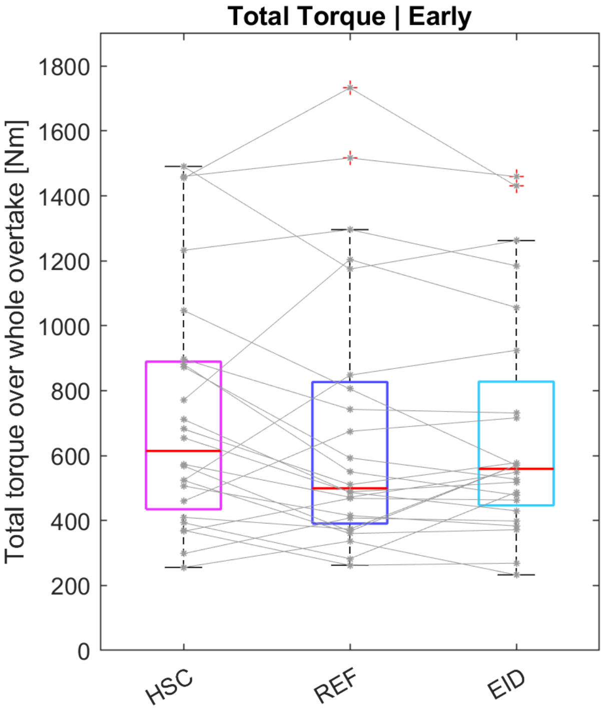
Early overtake

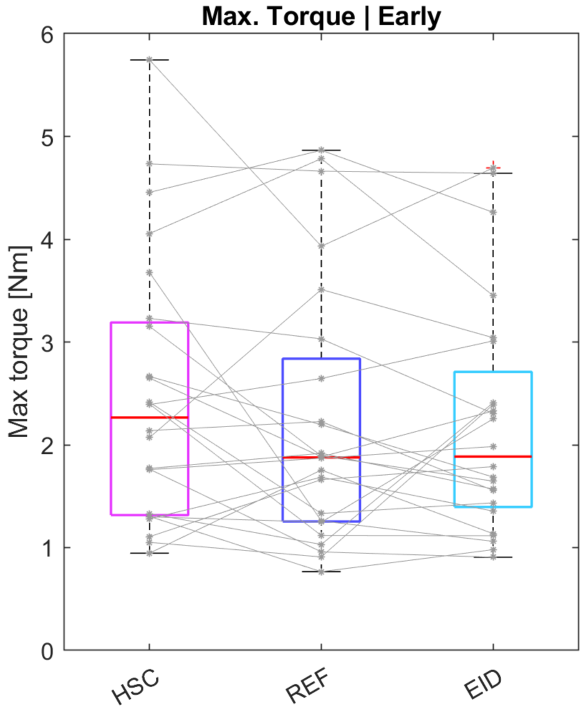




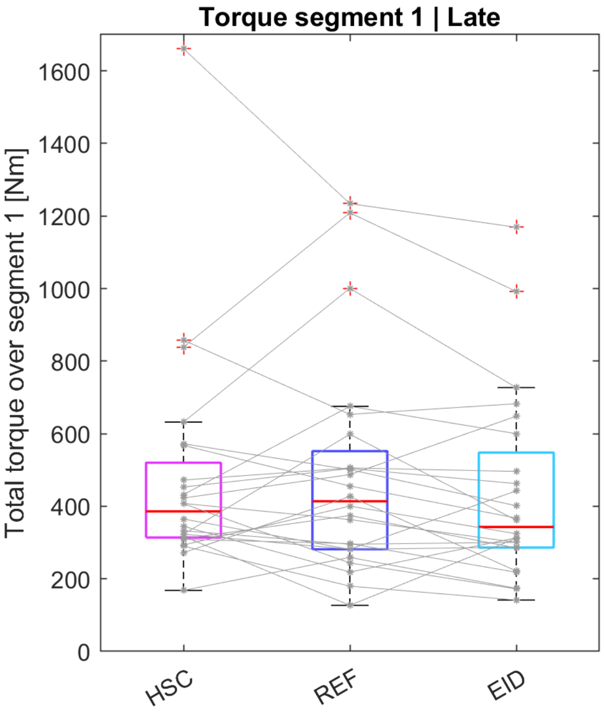


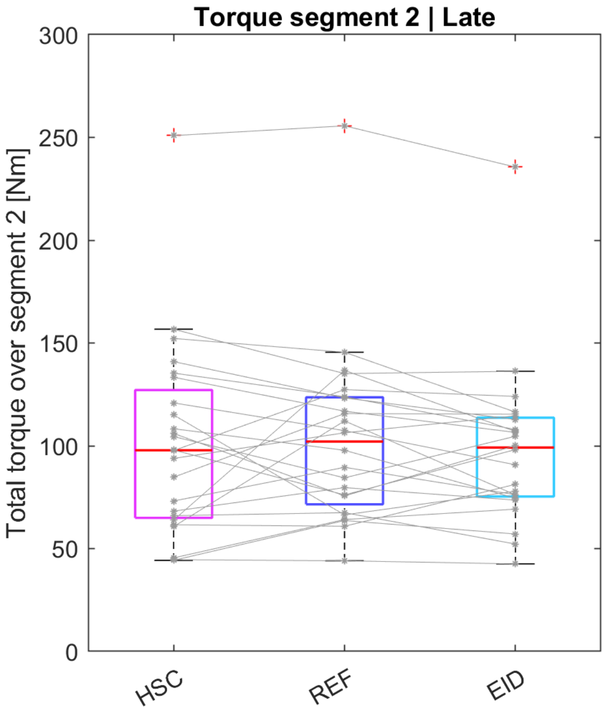


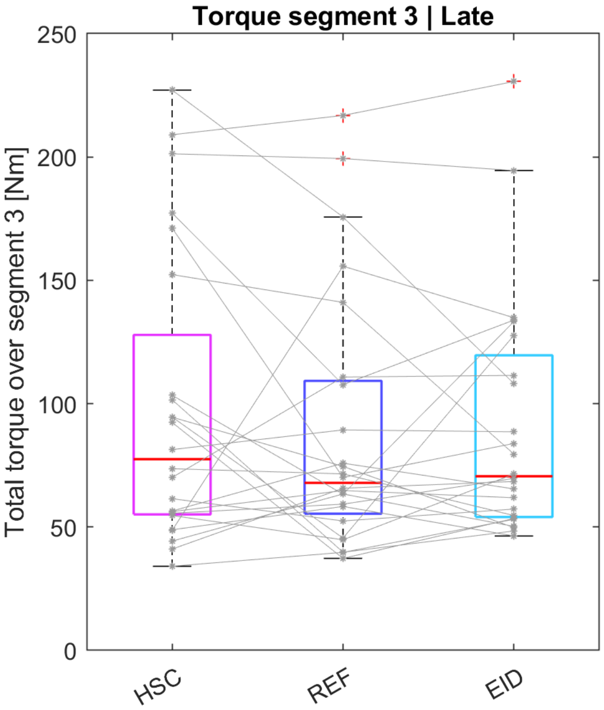

Total Torque | Early

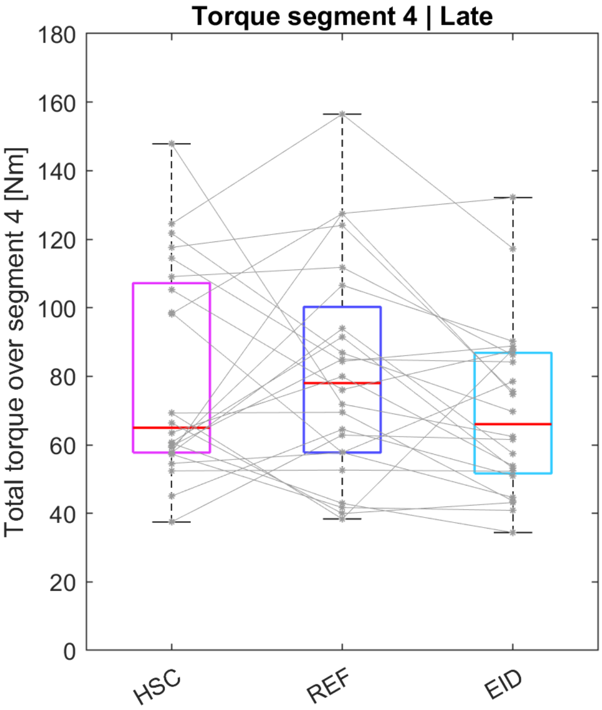

Max. Torque | Early

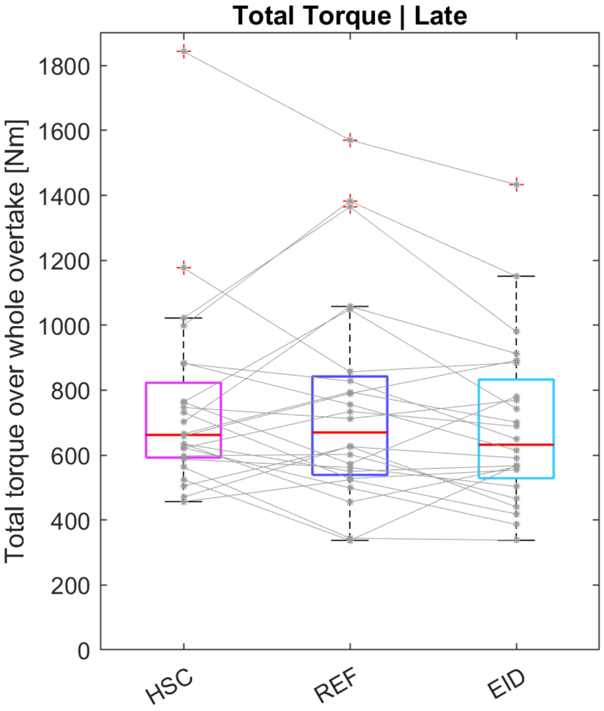
Late overtake

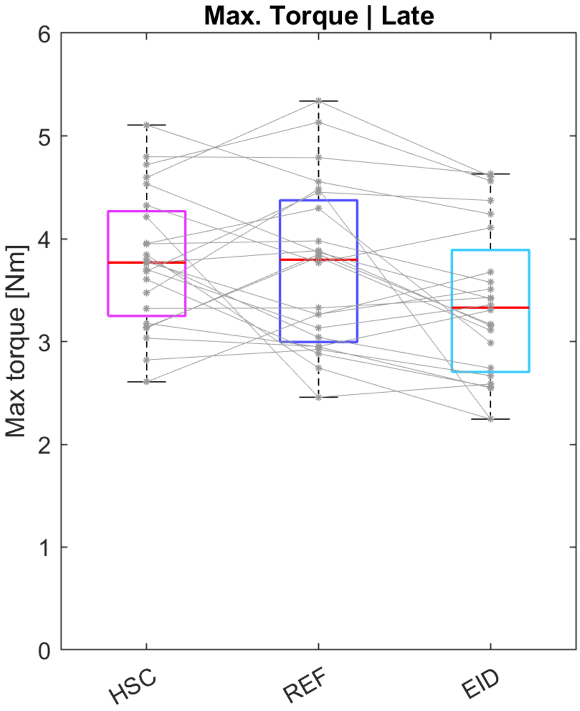

Torque segment 1 | Late


Torque segment 2 | Late


Torque segment 3 | Late


Torque segment 4 | Late


Total Torque | Late


Max. Torque | Late

G

Subsequent Analysis

Table G.1: Each participant is divided into a group according to their driven data with respect to HSC intended trajectory. Group 1 refers to ’fighters’, group 2 to ’followers’, group 3 to ’fighting no visuals’, group 4 to ’fighting inspired-EID’

Participant	Group	Comments
1	1	
2	1	
3	1	
4	4	2 overtakes not taken into account, which are not in line with driving behavior during other trials
5	-	No corresponding strategy compared to other participants, therefore not assigned to a group.
6	4	
7	4	
8	-	No corresponding strategy compared to other participants, therefore not assigned to a group.
9	1	
10	1	
11	4	
12	2	
13	-	No corresponding strategy compared to other participants, therefore not assigned to a group.
14	2	
15	3	
16	3	
17	4	
18	2	
19	2	
20	1	
21	3	
22	4	
23	3	
24	2	