Gaze Strategies in Skateboard Trick Jumps: Spatio-Temporal Constraints in Complex Locomotion

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Abstract

Purpose. This study aimed to further the knowledge on gaze behavior in locomotion by studying gaze strategies in skateboard jumps of different difficulty that had to be performed either with or without an obstacle. *Method*. Nine experienced skateboarders performed “Ollie” and “Kickflip” jumps over either an obstacle or over plane surface. The stable gaze at five different areas of interest was calculated regarding its relative duration as well as its temporal order. *Results*. Over the approach phase, an interaction between area of interest and obstacle condition, $F(3, 24) = 12.91$, $p < .05$, $\eta_p^2 = .62$, was found with longer stable-gaze locations at the take-off area in attempts with an obstacle ($p < .05$, $\eta_p^2 = .47$). In contrast, in attempts over plane surface longer stable gaze locations at the skateboard were revealed ($p < .05$, $\eta_p^2 = .73$). Regarding the trick-difficulty factor, the skateboarders descriptively showed longer stable gaze locations at the skateboard for the “Kickflip” than for the “Ollie” in the no-obstacle condition only ($p > .05$, $d = 0.74$). Finally, over the jump phase, neither obstacle condition nor trick difficulty affected gaze behavior differentially. *Conclusions*. This study underlines the functional adaptability of the visuomotor system to changing demands in highly dynamic situations. As a function of certain constraints, different gaze strategies were observed that can be considered as being highly relevant for successfully performing skateboard jumps.

Keywords: locomotion, perception-action-coupling, eye tracking, anticipatory behavior

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In the context of sports, the functional role of visual information processing for solving motor tasks has been extensively studied (e.g., Mann, Williams, Ward, & Janelle, 2007). In this regard, direct and indirect methods were applied to assess the link between gaze and sport performance, referring to the application of either gaze-registration systems (e.g., Kredel, Klostermann, & Hossner, 2015) or occlusions paradigms (e.g., Müller, Brenton, Dempsey, Harbaugh, & Reid, 2015). However, most of these studies investigated gaze behavior of participants in a more or less stable postural position like Vickers (1996) in her seminal study in which expert basketball players had to score baskets while standing at the free-throw line.

In contrast, gaze strategies for locomotor behavior were only investigated during walking. In this line of research, it was shown that natural gaze behavior should favorably be assessed in-situ as participants showed substantially different gaze strategies when walking a path compared to watching the exact same path from a first-person perspective (Foulsham, Walker, & Kingstone, 2011; see also Droll & Eckstein, 2009). Furthermore, Pelz and Rothkopf (2007) found that humans tend to visually focus the walking path more often in situations of uneven, wooded surfaces. This finding could be replicated by t'Hart and Einhäuser (2012) by additionally controlling for possible visual and context biases.

With regard to more complex locomotion, Patla and Vickers (1997) investigated participants' gaze behavior while stepping over obstacles of different heights. The results suggest that the processing of obstacle information is particularly linked to the pre-planning of the stepping movement since the participants did not fixate the obstacle during the stepping-over period (see also Mohagheghi, Moraes, & Patla, 2004). In addition, only the duration of last fixations at the obstacle was affected by the different obstacle heights elucidating the use of late information for regulating locomotion. This look-ahead gaze strategy was quantified by Patla and Vickers (2003) who showed that participants while walking over foot prints directed their gaze in the majority of cases two footprints ahead. This means that the visuo-motor system uses distal visual information to coordinate movements in a feedforward manner (Sailer, Flanagan, & Johansson, 2005).

When it comes to sports, it must be stated that these results can claim relevance for the multitude of sport tasks in which locomotion is required. In this domain, for instance, Vickers (2006) was able to reveal a look-ahead strategy also for expert ice-skaters who regularly anchor their gaze at the inside line and the tangent point of the ice oval. However, the particular requirement that has been previously sketched with respect to walking and that also is characteristic for sports has not been investigated so far, namely the spatial-temporal adaptation of the visuo-motor behavior to overcoming obstacles. Therefore, the current study aimed on the gaze behavior of experienced skateboarders performing two jump tricks of different difficulty either over plane surface or over an obstacle. On the one hand, this task is comparable to the locomotion tasks sketched above since an obstacle has to be passed so that the location of the take-off needs to be processed when planning details of the movement execution. On the other hand – and different from earlier investigations –, the handling of an additional object has to be taken into account so that the current feet position on the skateboard needs to be considered to be able to kick the skateboard at the respective position in order to lift it into the air. Furthermore, over the flight phase, continued visual information regarding the feet in relation to the skateboard might be required to prepare the complex landing.

Hence, for the experimental comparison, it was expected to find differences in gaze behavior as a function of jump difficulty as well as obstacle condition. In more detail, over the approach phase, skateboarders should show anticipatory gaze behavior at the take-off area to a higher degree in the obstacle than in the no-obstacle condition (cf., Patla & Vickers, 1997). Drawing on the empirical evidence on fixation durations as a function of task demands (e.g., Patla & Vickers, 1997), we further predicted longer stable-gaze locations at the board for the more difficult than for the easier technique. Finally, referring to the research on passing obstacles (cf., Mohagheghi et al., 2004; Patla & Vickers, 1997), one should not expect differences in gaze behavior over the flight phase.

Method

Participants

Twelve male skateboarders volunteered for the study and received individual analysis of their own gaze behavior in return. The raw data of three participants had to be excluded from further processing due to technical problems with the eye tracker in two cases and because one participant was not able to finish all four conditions. The remaining nine participants (age: 28.5 ± 4.7 years) had self-reported normal or corrected to normal vision. They were skilled skateboarders with on average 14.3 years (± 3.6 years) of experience. The approval of the ethics committee of the University Faculty and written informed consent from the participants were obtained in advance. The experiment was thus undertaken in accordance with the Declaration of Helsinki.

Apparatus

The skateboarders' gaze behavior over two movement phases ("approach" from start to take-off and "jump" from take-off to landing) were recorded with a mobile binocular eye-tracking system that was attached to custom-build swim goggles to minimize camera shifts (EyeSeeCam, EyeSeeTec GmbH, Fürstenfeldbruck, Germany). The EyeSeeCam (ESC, 60 Hz) is connected to a MacBook Pro via FireWire cable that is stored in a rucksack so that the skateboarders could move freely (see Figure 1). Via infrared reflection from the pupil and the cornea the ESC assesses the vertical and horizontal rotations of both eyes which are depicted as fixations cross in the footage of a scene camera that films the direction the head is aligned to. The accuracy of the ESC amounts to 0.5° of visual angle with a resolution of 0.01° root mean squared error. The video data from the ESC scene camera were also taken to subdivide a single trial into movement phases. The video data were cut with a self-written MATLAB script (Mathworks, Natick, MA, USA) and analyzed frame-by-frame using Kinovea 0.8.15 video chronometer and motion-analysis software (Boston, MA, USA). Finally, IBM SPSS Statistics 23 (New York, NY, USA) was used to conduct statistical analyses.

Insert Figure 1 about here

Procedure

The study was conducted on an outdoor, traffic-calmed part of a car-parking area. The ground was flat with refurbished pavement. The skateboarders always started at the same position marked by a cross from where they had to drive 12 m in a straight line into the jump zone which was 4 m long and 3 m wide. The jump zone was visually highlighted by alternating red and white stripes to the right and to the left. All skateboarders used their own skateboard.

Participants’ task was to perform two common skateboard tricks, either an “Ollie” or a “Kickflip”. The “Ollie” is a no-handed aerial jump in which the skateboarder and the skateboard leap into the air without the use of the rider’s hand. Likewise, the “Kickflip” is a no-handed aerial jump with an additional 360° twist of the skateboard around its longitudinal axis. Consequently, the “Ollie” is the easier technique than the “Kickflip”. In the obstacle condition, an obstacle was placed at a distance of 14 m from the start position, that means, exactly in the mid of the jump zone (see Figure 1). Due to safety reasons, the respective obstacle differed for the two jump techniques. Whereas for the “Ollie” jump a laterally positioned customary skateboard was used (obstacle height 20 cm), for the more difficult “Kickflip” jump the skateboard was replaced by a pipe which was slightly lower in height (obstacle height 12.5 cm). Pilot testing showed that using the pipe also for the easier “Ollie” might fail the manipulation since the skateboarder reported no relevant difference in comparison to jumping without an obstacle. However, as pilot skateboarder at the same time denied to jump over the skateboard with the more difficult “Kickflip” technique, the experimental setup had to be slightly adapted as sketched before.

The skateboarders attended individual sessions. After having read the instructions, a warm up was performed before as well as after fitting the ESC system. Subsequently, the ESC was calibrated by consecutively fixating five dots that were displayed by means of a laser pattern in a regular grid with a distance of 8.5° of visual angle between the dots. Measurement accuracy of the ESC was verified after every jump by controlling the position of the fixation cross while the participant was fixating several objects and the system was recalibrated if necessary.

After the calibration, the skateboarders started with their first trial. In sum, four successful attempts, that means, jumps according to the technique guidelines, had to be performed in 2 (technique) times 2 (obstacle) conditions, each. The order of the conditions was counterbalanced with the restriction that both obstacle conditions were consecutively tested for the same jump. At the end of the session, the participants were thanked and debriefed about the objectives of the study. The data collection for each participant lasted about 60 minutes.

Data Analyses

All analyses were conducted with the video data files recorded by the ESC system. First, movement phases were manually identified by coding the moments of start of the trial (first frame the skateboard moved into the direction of the jump zone), take-off (first frame the skateboard's tail was touching the ground) and landing (first frame one of the skateboard's wheels touched the ground). Participants' gaze behavior was also analyses manually resulting in durations of stable-gaze locations of the fixation cross, defined as periods of time over which the gaze vector remained within the same area of interest for at least 6 video frames (i.e., 100 ms). For the allocation of the gaze to a certain location, five areas of interest had been defined a priori: (a) the skateboard, (b) the take-off area, (c) the jump zone, (d) the landing area, and (e) the obstacle (for the obstacle conditions only). For the areas of interest (b) and (d), whose location could vary from trial to trial due to the actual performance of the jump, the boundaries of the respective area were identified as a circle with the skateboard's length as diameter and the resulting spots were marked in the video footage as patches allowing for the allocation of the gaze vector. Further potential cues (e.g., the approach route) were not expected to be relevant for the task at hand and thus not coded.

Movement phases. For the movement phases, the average duration of the approach (from start until take-off), the average duration of the jump (from take-off until landing) and the average total duration (from start until landing) were calculated out of 4 attempts for each of the 2 (technique) x 2 (obstacle) conditions. The movement phases were analyzed with a 2 (phase) x 2 (technique) x 2 (obstacle) ANOVA with repeated measures on all factors.

Gaze behavior. The relative gaze duration (% of overall phase duration) at the five different areas of interest was calculated out of 4 trials for each of the 2 (technique) x 2 (obstacle) conditions for the approach and the jump phase separately. Relative values were preferred over absolute values in order to compensate for different overall phase durations between the two techniques (“Ollie”, approach: min = 3085.4 ms, max = 5104.2 ms; jump: min = 418.8 ms, max = 543.8 ms; (“Kickflip”, approach: min = 3247.9 ms, max = 6233.3 ms; jump: min = 406.3 ms, max = 628.5 ms). In addition, the percentage of stable gaze behavior (% of trials) was further analyzed over (absolute) time by triggering all trials onto the moment of take-off and calculating the percentage score for average stable gaze locations at the five areas of interest for each time step (of 16.7 ms) before and after this event, separately for both techniques and obstacle conditions, respectively. This basically means that, for example, if all participants in half of the trials would show a stable gaze at the jump zone at the moment of take-off, the respective value for jump zone would be 50 %. Finally, out of values for each participant, a running Cohen’s *d* was calculated for the respective comparison to assess the relevance of differences in the area-of-interest-related percentage scores. Separately for the approach and jump phase, the relative gaze duration was subjected to a 4 (area of interest) x 2 (technique) x 2 (obstacle) ANOVA with repeated measures on all factors. Due to the standardization, it was not possible to add “phase” as third factor in this calculation. Finally, for the obstacle conditions, the relative duration of gaze located at the obstacle was analyzed with dependent t-tests.

For all ANOVAs, significant main and interaction effects were further analyzed with planned t-tests. In cases of sphericity assumption violations Greenhouse-Geisser corrections were applied. A posteriori effect sizes were computed as partial eta squares (η_p^2) and Cohen’s *d*. The level of significance was set at $\alpha = .05$.

Results

Movement Phases

For movement phases, a significant main effect for phase, $F(1, 8) = 157.38$, $p < .05$, $\eta_p^2 = .95$, was found with longer durations for the approach ($M = 4543.9$ ms, $SD = 884.2$ ms) than for the jump ($M = 483.9$ ms, $SD = 71.8$ ms) phase. In addition, a significant main effect for technique, $F(1, 8) = 23.83$, $p < .05$, $\eta_p^2 = .75$, and a significant phase x technique interaction, $F(1, 8) = 21.44$, $p < .05$, $\eta_p^2 = .73$, was revealed, elucidating significant technique differences in the approach phase, $t(8) = 4.75$, $p < .05$, $d = 0.85$, but not in the jump phase, $t(8) = 1.68$, $p > .05$, $d = 0.31$, $1\text{-}\beta = .13$. The skateboarders approached the jump zone faster in the "Ollie" condition ($M = 4165.3$ ms, $SD = 810.9$ ms) than in the "Kickflip" condition ($M = 4920.7$ ms, $SD = 957.4$ms). No further significant main and interaction effects were revealed (all ps $> .05$, all $\eta_p^2 < .05$, all $1\text{-}\beta > .12$) highlighting that the skateboarders performed the respective jump in both obstacle conditions in a similar way.

Gaze Behavior

Relative gaze duration: Approach phase. The ANOVA for relative gaze duration revealed a significant main effect for area of interest, $F(3, 24) = 10.67$, $p < .05$, $\eta_p^2 = .57$, as well as significant area of interest x obstacle, $F(3, 24) = 12.91$, $p < .05$, $\eta_p^2 = .62$, and area of interest x technique x obstacle interactions, $F(3, 24) = 3.37$, $p < .05$, $\eta_p^2 = .29$. Independent of technique and obstacle the skateboarders stabilized their gaze longest at the skateboard ($M = 25.6\%$, $SD = 18.6\%$), followed by the take-off area ($M = 14.1\%$, $SD = 10.6\%$) and jump zone ($M = 10.3\%$, $SD = 6.1\%$), and shortest at the landing area ($M = 0.4\%$, $SD = 6.2\%$).

For skateboard as an area of interest, a significant main effect for obstacle, $F(1, 8) = 21.67$, $p < .05$, $\eta_p^2 = .73$, and a significant technique x obstacle interaction, $F(1, 8) = 5.98$, $p < .05$, η_p^2

= .43, was found with shorter gaze durations in the obstacle (*M* = 16.8%, *SD* = 13.6%) than in the no-obstacle conditions (*M* = 34.4%, *SD* = 23.6%) and descriptively longer stable-gaze durations for the “Kickflip” (*M* = 39.5%, *SD* = 27.4%) than for the “Ollie” (*M* = 29.4%, *SD* = 19.7%) in the condition without obstacle, $t(8) = 2.21$, $p > .05$, $d = 0.74$. For the take-off area, longer stable-gaze durations (*M* = 21.4%, *SD* = 15.0% vs. *M* = 6.9%, *SD* = 6.2%), $F(1, 8) = 7.11$, $p < .05$, $\eta_p^2 = .47$, and for the jump zone (*M* = 7.75%, *SD* = 6.1% vs. *M* = 12.8%, *SD* = 6.2%) shorter stable-gaze durations, $F(1, 8) = 8.39$, $p < .05$, $\eta_p^2 = .51$, were found for the obstacle than for the no-obstacle condition. No further significant main and interaction effects were revealed (all *p*s > .05, all $\eta_p^2 < .19$, $1\text{-}\beta > .07$). For obstacle as area of interest in the trials with an obstacle – that could not be included in the ANOVA –, no significant difference was found between “Ollie” (*M* = 12.9%, *SD* = 19.1%) and “Kickflip” (*M* = 4.1%, *SD* = 7.2%), $t(8) = 1.62$, $p > .05$, $d = 0.53$, $1\text{-}\beta = .29$. Summing up, in terms of effect sizes, the most important effect was revealed not with respect to the technique but with respect to the obstacle factor with longer stable-gaze durations on the skateboard in the obstacle than in the no-obstacle conditions and longer stable-gaze durations on the take-off area in the no-obstacle than in the obstacle conditions.

Relative gaze duration: Jump phase. For the relative gaze duration in the jump phase a significant main effect for area of interest was found, $F(3, 24) = 39.01$, $p < .05$, $\eta_p^2 = .83$, with the longest gaze duration at the skateboard (*M* = 77.1%, *SD* = 35.6%) followed by the remaining three areas of interest that did not significantly differ from each other (all *p*s > .05, all $1\text{-}\beta > .79$). No further significant main effects and interactions were found (all *p*s > .05, all $\eta_p^2 < .11$, all $1\text{-}\beta > .09$). Likewise, no significant difference for technique (“Ollie”: *M* = 1.8%, *SD* = 3.9%; “Kickflip”: *M* = 0.0%, *SD* = 0.0%) was revealed for the obstacle as specific area of interest in the obstacle conditions, $t(8) = 1.29$, $p > .05$. This means that under all conditions, directing the gaze to the skateboard was found to be most important over the jump phase.

Percentage of stable gaze. The percentage of stable gaze at the areas of interest skateboard, take-off area and jump zone for the two obstacle conditions are depicted in the upper panel of Figure 2 as a function of (absolute) time using the moment of take-off as a trigger (= 0 ms). As the previous descriptions revealed no relevant percentage of gaze allocations to the landing area as fourth a-priori defined area of interest, these data have been excluded from the illustration for the sake of clarity. In the lower panel, running Cohen's *d* values are displayed for the area-of-interest-related comparisons between the two obstacle conditions. In both panels, the two black vertical lines denote the average jump phase.

Insert Figure 2 about here

For skateboard as an area of interest, the percentage of stable gaze increases over time for both conditions with the highest value at 300 ms after the take-off. However, in the no-obstacle condition, the percentage starts to increase at around 2000 ms before take-off with a first peak at around 200 ms before take-off whereas, in the obstacle condition, virtually no stable gaze can be observed until 250 ms before take-off with a rapid increase from this moment and catching up with the no-obstacle condition shortly after the moment of take-off. This spread between the two obstacle conditions can also be seen in the running Cohen's *d* graph with almost linearly increasing values until about 250 ms before take-off, peaking at a value of *d* = 4.94, and a rapid decrease after that point in time.

In contrast, for the take-off area as an area of interest, the opposite was observed with increasing percentage scores for the obstacle condition in the early phase until 450 ms before the moment of take-off whereas virtually no stable-gaze on the take-off area was found for the no-obstacle conditions. This difference is represented in the running Cohen`s *d* illustration by a maximum value of *d* = 4.14 at about 450 ms before take-off. Over the jump phase, the skateboarders did not stabilize their gaze at the take-off area.

Finally, the percentage scores for a stable-gaze location at the jump zone was overall smaller than for the two other areas of interest. Between about 2500 ms and 1500 ms before take-off the skateboarders showed slightly higher values for a stable gaze at the jump zone in the no-obstacle condition than in the obstacle condition. The relevance of this difference is represented in the Cohen's *d* values peaking about 2200ms before take-off at *d* = 2.96.

Discussion

In the current study, the gaze behavior of experienced skateboarders was investigated when performing trick jumps of different difficulty over an obstacle on the one hand and over a plane surface on the other hand. Whilst the expected difference in gaze behavior as a function of trick difficulty was not empirically found, the obstacle-related hypothesis could be confirmed since the analyses of the gaze behavior revealed an interaction between obstacle and area of interest. This interaction illustrates that over the approach phase the skateboarders apply different gaze strategies if they have to perform the jumps either over an obstacle or over a plane surface. Over plane surface, predominantly visual information regarding the skateboard is processed whereas, if the jumps must be performed over an obstacle, information about the take-off area are continuously updated over the approach phase until shortly before the moment of take-off (for the predictive function of visual perception, see also, e.g., Sailer et al., 2005).

With regard to underlying motor-control processes, it should be particularly noted that it is not the stable gaze at the obstacle that characterizes gaze behavior in the obstacle condition (with a maximum score of 21.9 % about 700 ms before take-off). Instead, the gaze is stabilized at the take-off area, that means, at a visual cue that is available in both obstacle conditions. These findings imply that the skateboarders apply two different strategies when preparing the jump movement. In the case of an obstacle, the exact timing of the take-off needs to be planned to avoid a collision such that it is crucial to continuously update information about the distance to this point (cf. optical-flow from a psycho-ecological perspective, Gibson, 1950). In contrast, in the case of a plane surface, the skateboarders were only instructed to perform the jump within a certain jump zone such that motor planning could be predominantly directed to the mere execution of the jump which is reflected in the preferred stable-gaze location at the feet on the skateboard. In sum, these findings highlight the close link between action and perception such that differing demands for the motor-control systems directly affected the timing of the processing and the selection of visual information. The bi-directionality between these two domains was, for example, shown by Amazeen, Amazeen, Post, & Beek (1999) who found that constraining visual information processing with liquid crystal googles results in adaptations within the timing of a throw and catch cycle (for an overview, e.g., Schütz-Bosbach & Prinz, 2007).

Regarding effects of trick difficulty, the only found tendency refers to the stable-gaze location at the skateboard as a function of jump difficulty which was revealed solely for the obstacle condition over the approach phase. Nevertheless, this result corroborates earlier findings on the relation between task demands and foveal information processing (e.g., Patla & Vickers, 1997) hypothesizing that longer intervals for visual information processing are required as a function of fine-tuning demands over movement planning (e.g., Vickers, 1996) as well as over online-control of the movement execution (e.g., Klostermann, Kredel, & Hossner, 2014). However, since the respective inferential test (marginally) missed the predetermined level of significance, this interpretation has to be treated with care.

Finally, the gaze data on the jump phase clearly showed that, after the moment of take-off, neither trick difficulty nor the presence or absence of an obstacle affected gaze behavior. This finding suggests that difficulty- or obstacle-related visual information – although having been definitive, as shown before, for the planning of the jump movement – is not further used for the online-control of the jump phase. Instead, the direction of the gaze to the skateboard under each condition implies that for the preparation of a save landing information on the relation between the own body and the skateboard becomes crucial. This interpretation would be perfectly in-line with the above-suggested conclusion that locomotion control in complex sports environments is mainly affected by the question whether the current movement needs to be spatio-temporally adapted to relevant obstacles or not.

As for the majority of eye-tracking studies the mobile measuring devices need to be considered as limiting factor which might have affected the skateboarders' natural movement and gaze behavior. The rather long warm-up phase in which the skateboarders had as much time as required to accustom themselves with the setup definitely minimized possible negative effects. Nevertheless, the results have to be treated with caution.

What Does This Article Add?

To the best of our knowledge, this is the first study to investigate gaze behavior in a complex and highly dynamic locomotion task like performing skateboard tricks. In sum, the results illustrate a strong link between specific task demands and visual information processing, thereby further underlining a close coupling between action and perception in motor performance: As a function of specific constraints for the motor-control system, different gaze strategies were observed to successfully perform the jump tricks. With regard to surface plausibility, the revealed strategies can claim to reflect functional characteristics of perceptual-action coupling. However, as the gaze behavior was not manipulated in the study at hand, further research would be needed in which the actual functionality of these strategies is experimentally addressed.

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Author's Note

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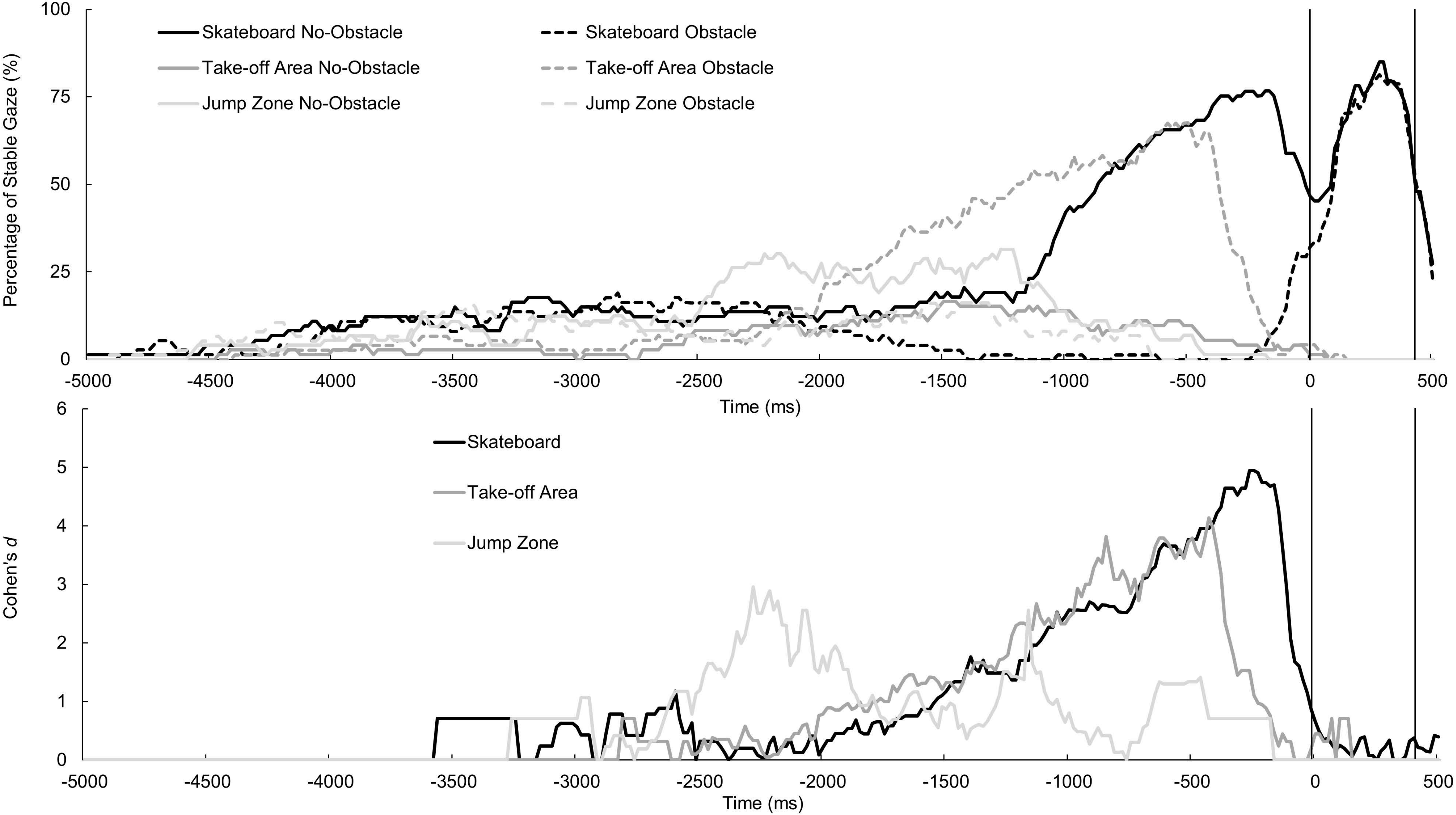
100
75
50
25
0
Percentage of Stable Gaze (%)
Skateboard No-Obstacle
Skateboard Obstacle
Take-off Area No-Obstacle
Take-off Area Obstacle
Jump Zone No-Obstacle
Jump Zone Obstacle
-5000
-4500
-4000
-3500
-3000
-2500
-2000
-1500
-1000
-500
0
500
Time (ms)
6
5
4
3
2
1
0
Cohen's *d*
Skateboard
Take-off Area
Jump Zone
-5000
-4500
-4000
-3500
-3000
-2500
-2000
-1500
-1000
-500
0
500
Time (ms)