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Bachelorarbeit

Stimulus Generation Software for the Analysis of Smooth Pursuits

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Kurzfassung

Um sich bewegende Objekte mit den Augen zu verfolgen nutzen Menschen eine Kombination aus “smooth pursuit” und sakkadischen Augenbewegungen, um das Objekt erneut auszurichten, falls dies notwendig sein sollte. In dieser Arbeit soll es vor allem um erstere Augenbewegung gehen. Verwandte Arbeiten haben sich mit dem Einfluss von sich bewegenden Hintergründen und auch bewegten Ablenkungen beschäftigt. Jedoch wurde hier nicht erforscht, wie sich Objekte, die den Pfad des Ziels kreuzen, auf Augenbewegungen auswirken. In diesem Sinne haben wir eine Studie durchgeführt, welche drei verschiedene Aspekte untersucht: **(a)** die Geschwindigkeit des Ziels, **(b)** horizontale und vertikale Pfade und **(c)** die Anzahl der Ablenkungen. Um die Videos für die Studie zu generieren haben wir eine Software implementiert. Unsere Ergebnisse zeigen, dass die Geschwindigkeit einen Einfluss darauf hat, wie gut Menschen dem Ziel nachschauen können. Wir zeigen, dass sie einen signifikanten Effekt auf mehrere abhängigen Variablen, wie **(a)** die Differenz zwischen der Position des Ziels und dem Punkt, den die Teilnehmer anschauten, **(b)** die Zeit die sie das Ziel anschauten und **(c)** die Anzahl an Übergängen von dem Ziel auf eine Ablenkung, hat. Die zwei verbleibenden unabhängigen Variablen (Anzahl an Ablenkungen und Achse) hatten keinen großen Einfluss auf die Leistung des Teilnehmers.

Abstract

To follow moving objects, humans use a combination of smooth pursuit eye movements and saccadic ones to realign the target if necessary. This thesis addresses the first kind of eye movement. Related work shows, how moving backgrounds or distractors influence smooth pursuit eye movements. However, it is uncertain how objects which intersect the trajectory of the moving target impact these kinds of eye movements. In this regard, we conducted a study to investigate how different factors impact these. At first, we implemented a software which creates video stimuli for the study. We researched three different aspects: **(a)** target velocity, **(b)** horizontal and vertical trajectories and **(c)** the number of distractors. Our results show that the target speed had an impact on people's performance of smooth pursuit eye movements. We show that this had a significant influence on multiple dependent variables, like the offset between the gaze point and the actual position of the target, the time the participants looked at the target and the transitions from the target to any distractor. The two remaining independent variables (number of distractors and axis) did not have a high influence on the performance of the participants.

Contents

List of Figures

List of Tables

List of Listings

List of Abbreviations

AOI area of interest. 33, 37, 38, 40, 43, 45, 79

SPEM smooth pursuit eye movement. 13, 15, 16, 17, 18, 19, 43, 45

WPF Windows Presentation Foundation. 19, 20, 21

1 Introduction

In everyday life, there are situations where people want to follow a moving object. These can occur when driving in a car and following for instance a cyclist crossing the road, or outside in the nature when birds fly by. These kinds of eye movements are called smooth pursuit eye movements (SPEMs), they are typically characterized by a steady speed and little or no acceleration. It is necessary for humans to perform this kind of eye movement to keep the moving object in focus. In order to achieve this, the image must be as close to the centre of the fovea as possible, since this is the region of the retina where the visual acuity can be maximised [CT84]. Eventually, the eye movement will be adjusted to the velocity of the moving object and can be maintained for some time. Sometimes so-called catch-up saccades are used to realign the image when the person misjudged the speed or due to a short lack of attention. Moreover, this effect can be the other way around, if the object moves slower than the eyes back-up saccades are required.

In contradistinction to fixations and saccades, SPEMs are not as well researched. However, there is some work on them, regarding for instance the trajectories and latency of target selection. Most of the early work focuses on how these kinds of eye movement can be initiated and how people behave when they have to track different paths and targets [FL95; OK99; PW80; Rob65]. While these results improve the performance of recognizing smooth pursuits, there is research about the cognitive side of performing SPEMs, as well. It is known, that there are many factors like prediction, experience, attention and the mental health of subjects, which can influence SPEMs [Bar08].

We conducted a study on SPEMs and how different factors influence them. Therefore, we implemented a software to create short video clips which contained different moving targets to analyse SPEMs. The initial requirements for this system were a graphical user interface and variable options regarding the settings of the video. In this study, we then used the created videos to have the subjects perform SPEMs in the presence of different numbers of distractors. In addition, we will use vertical and horizontal moving targets to investigate if any possible effect of distractions is more or less present when doing different eye movements. The last part of our research will be the influence of velocity on the subject's performance. We want to know, if distractors moving orthogonally to the target and intersecting at some point, have an effect on SPEMs.

At first, the related work will be described, containing the basic mechanisms of SPEMs, cognitive processes and factors which influence them. Thereafter, the system which was used to create the video stimuli for the study will be described. The fourth chapter explains everything about the conducted study, and the results are described afterwards. The last chapter summarises the thesis and contains future work, as well.

2 Related Work

This chapter is split into three sections, the first describes basic mechanisms of SPEMs and the second one contains cognitive processes involved in these kinds of eye movements. The third part focuses on possible distractions when performing smooth pursuits.

2.1 The basic mechanisms of smooth pursuit eye movements

When it comes to investigating SPEMs, there are several possibilities to initiate these eye movements. This section describes, how different target velocities, trajectories or the appearance and spatial position affects the performance of subjects when tracking a target. Basic information will be provided here, for further influences see also Section 2.2 on the following page and Section 2.3 on page 17.

Velocity There are different velocities, at which humans are capable of performing SPEMs. The most common unit of this velocity is degrees per second, because the angular velocity is independent from the distance between the participant and moving objects (for a detailed description on how to calculate this see [HNA+11, p.23 f.]). Most of the time, a typical SPEM velocity is between 5 °/s and 20 °/s [Rob65; WES54], but there is some literature which states that this range should be between 10 °/s and 30 °/s [DKA18; HNA+11, p.23]. Although it should be below 30 °/s to avoid catch-up saccades [HNA+11, p.329], humans can perform SPEMs at much higher velocities [MLR85].

Trajectory There is a variety of different paths, which can be used to initiate SPEMs. Popular ones are geometric shapes, like circles [EVBG15; KAB15; ŠIK+16; VBG13] or squares and rectangles [DKA18; PVT+13]. Further trajectories are linear ones [KAB15; VBG13; VPBG13], and the second category would be waveforms. This could be a typical sine wave, harmonic waveforms or triangular waves [Bar08]. Aside from these, ramp and step-ramp trajectories are used as well to delay the first occurrence of a saccade [Bar08]. Furthermore, most humans are better at following horizontal paths than vertical ones [RZD+96]. The early work by Rottach et al. [RZD+96] also shows, that the vertical eye movement for most people is easier downward than from the bottom to the top. They also found out that sinusoidal and triangular target motions are harder than linear ones, as well.

Appearance and spatial position In everyday life, there are some possibilities to perform SPEMs, for instance a car moving through the city would be a good target to follow alone with the eyes. For research purposes, mostly a circular or rectangular shape is used as a target with various colours, which can be tracked easily [BF85; BM83; CT84; KB04; KHW+18; KMP84; LI06; PW80; TL86].

Furthermore, Dubois and Collewijn investigated the placement of objects in the field of view and they conducted a study, which indicated “that the fovea is more powerful than the periphery in eliciting optokinetic pursuit” [DC79, p.1105]. This indicates that the shape and colour of the target are not as important as the spatial position, especially because “smooth pursuit movements are usually thought to be guided only by target velocity” [PW80, p.523].

2.2 Cognitive processes involved in smooth pursuits eye movements

SPEMs require different kinds of mental efforts, which have been investigated in the past years. One of the main parts are prediction processes, but attention and expectation are also influencing factors [Bar08]. The following section first describes, how cognitive processes are involved in SPEMs and afterwards, how these can be used in tests.

2.2.1 Prediction processes of smooth pursuit eye movements

There is evidence that humans can predict the future path or the velocity of moving targets under certain circumstances. These kinds of processes are used to “overcome delays in the processing of sensory information [and to] temporarily dissociate [from] sensory input” [Bar08, p.319].

Studies, which include conditions where the target is not visible the whole time indicate that people can perform SPEMs for a short time even without an object to follow. Early work by Becker and Fuchs [BF85] investigated the effect of disappearing targets on smooth pursuits. Here, the participant was instructed to follow a moving target horizontally at a constant speed, which was not visible at random times for a different amount of time. The results indicated that the target needs to be visible for 300 ms in order to continue SPEMs for a short time. Another interesting fact was that shortly after the target disappeared, the eye velocity decreased until it reached a certain level and stayed at this velocity thereafter.

Mattusch et al. [MMK+18], for instance studied the effect of hiding parts of the trajectory and how people can follow it without this information as well. They detected a correlation between the amount of the trajectory that was still visible and the performance of the participants, which was good if 25% was hidden and still acceptable (but worse) when 50% was hidden. Another effect was the amount of the trajectory the participant followed the moving object before it disappeared. According to their results, people can guess better where the object will be if at least 25% of the trajectory is visible before it vanishes. This supports the findings of Becker and Fuchs [BF85].

Although these above studies show a correlation between smooth pursuits and prediction, there is also work on how learning and past experience can affect SPEMs. For instance, “when the subject tracks a regular periodic waveform phase errors are smaller than when tracking a more irregular or randomised waveform” [Bar08, p.319]. Bahill and McDonald [BM83] investigated this effect by training participants to follow sinusoidal or simpler waveforms. Their results showed that subjects were able to perform SPEMs without any latency and reduced positional errors for targets moving at a continuous speed.

Some of the first researchers to find a correlation between SPEMs and experience were Kowler et al. [KMP84]. Their study showed, that “taking expectations into account is both necessary and feasible. Taking expectations into account, quantitatively, allows accurate predictions about smooth eye movement velocity when target motions are unpredictable”[KMP84, p.197]. Additionally, Kowler and Steinman [KS79a; KS79b] addressed the correlation of expectation and target movements. They showed that expectation would always have an influence on eye movements, especially when the target moves at slow speeds.

2.2.2 Using smooth pursuit eye movements as cognitive tests

As described above, SPEMs involve different cognitive processes and can therefore be used as a test. On the one hand, it has been used to measure cognitive workload and on the other hand to detect psychiatric disorders as described in the following section.

Kosch et al. [KHW+18] used SPEMs to measure cognitive workload by conducting a study, where subjects were asked to follow a moving target while tasks of various degrees of difficulty had to be performed. They used the N-back task by Mehler et al. [MRD11] and their results showed a gaze difference of SPEMs with a higher level of cognitive workload. The distinction of velocity as another kind of cognitive workload showed that both types of mental efforts affect SPEMs in a different way. They used a questionnaire to measure the mental demand, and people did not mark a higher score when the velocity of the target increased.

Since SPEMs require different kinds of mental effort, they can be used to investigate psychiatric disorders. For instance to identify schizophrenia, cognitive factors like “attention, selection, expectation, working memory, prediction and mismatch detection” [Bar08, p.323] are used. As Barnes [Bar08] explains, SPEMs “operate[] on the basis of predicting future movement and using visual feedback to check that the prediction is correct” [Bar08, p.323]. He also describes that according to these cognitive factors, SPEMs could be used to indicate deficiencies, but this requires tasks that isolate the different mental factors, like for instance “[a]ttention, which is often deficient in schizophrenia, [but] plays a large part in pursuits” [Bar08, p.323].

2.3 Influencing factors on smooth pursuits

There is work on different factors, which can influence the ability of people to perform smooth pursuits. This mainly focuses on distractions, like moving or stationary distractors or alternatively the presence of a moving or structured background.

2.3.1 The effect of different backgrounds

A different factor that influences the ability to perform smooth pursuits is the background. Barnes claims, that it is “more difficult to track a target against a structured rather than a blank background” [Bar08, p 316]. According to this, Lindner et al. [LSI01] conducted studies to analyse the effect of a moving structured background on smooth pursuits. The first one investigated the effect of background motion and showed, that background movements in the opposite direction as the target have less impact on smooth pursuits than the movement in the same direction. The second study researched the effect of background velocity. Here, the results are, that only the fastest moving background (22 °/s) with a target velocity of 11 °/s had a significant effect on the eye movement.

Finally, the last study was about the separation of object and background depth. This indicated that movements in three different depth planes were comparable, so there is also no effect on smooth pursuits.

Collewijn and Tamminga [CT84] investigated the effect of different backgrounds on SPEMs as well and they found, that "[t]he influence of a diffusely illuminated background was minimal. A structured background inhibited smooth pursuit in the horizontal direction by about 10% and in the vertical direction by about 20%" [CT84, p.217]. These results indicate that optokinetic backgrounds only have a small influence on SPEMs. We did not want to analyse the effect of a moving background, so we used a stationary one.

2.3.2 Smooth pursuits and distractors

There is also work on how the presence of distractors influences the latency of the SPEM. Ferrera and Lisberger [FL95] for instance investigated the effect of moving distractors on SPEMs. They used two monkeys, which should follow a moving target. To distinguish the distractor, they used different colours and all objects moved at the same speed. This study showed that a distractor increased the latency when moving in the opposite direction. This was also confirmed in another experiment, which did not rely on the visual clue of colour when selecting the target, but the spatial position. Here, the latency increased as well in the condition where the distractor moved in the opposite direction. Ferra and Lisberger [FL97] did a follow up study on this particular topic to investigate, whether any further directions or speeds of the distractor influence SPEMs. As they found out in the previous study, the direction of the distractor has an influence on the latency, but they could not confirm that the speed has a great impact.

Knox and Bekkour [KB04] also studied the effect of a distractor on smooth pursuit latency. Here, one stationary distractor was used to investigate the effect of the spatial placement, while the participants were asked to follow a moving target as well. They "found that while a stationary distractor presented in the contralateral visual field and part of the ipsilateral visual field increased pursuit latency in an eccentricity dependent manner, a distractor presented in the ipsilateral visual field, within 45° of the axis along which the pursuit target moved, had no effect on latency" [KB04, p.494]. This result confirms the findings of the study described above by Ferra and Lisberger [FL95].

Since we want to investigate the effect of distractors on SPEMs, when the trajectories of both the target and distractor intersect at some point, we decided to start the target always in the centre of the screen to avoid latency effects of having to choose the target to follow.

3 System

The following chapter describes the system, implemented by using the technologies described in the following section. Figure 3.1 on the following page shows the user interface of the application. This system was used to create the video stimuli for our study. These were used to collect the data we wanted to analyse later. Since moving objects are necessary to perform SPEMs, we animated a target moving across the video with different settings. We used different speeds and trajectories to test if any of that influences these kinds of eye movements.

3.1 Technologies

This section describes the technologies, which have been used to create the Software. One of the requirements was to design a graphical interface, which can create videos, with several input possibilities to manipulate the properties of the video and the displayed objects. Therefore, a suitable system is Microsoft's Windows Presentation Foundation (WPF).

3.1.1 Windows Presentation Foundation

WPF is a subset of the .NET Framework; it uses DirectX and replaces "Windows Forms", the former graphical subsystem by Microsoft. It was first introduced in 2006 with the .NET Framework 3.0 and is supported by multiple windows versions [Weg12, p. 3]. It is free to use, since all compilers are included in the Framework, but working with for example Visual Studio[1] simplifies building the application. There are multiple other helpful systems like Expression Blend for Visual Studio, which can be used by graphical designers [Weg12, p. 4].

One main aspect of WPF is the differentiation of the graphical component and the code behind. This allows designing the application independent of the actual functionality. To design the application the markup language "eXtensible Application Markup Language" (XAML) is used. This means for instance all input fields or the displayed text that the user can read is written in this language in a separate file. Everything can be accessed in the corresponding C# file, which contains the interaction logic of the application. Alternatively, the system can be written in Visual Basic. This can be simple logic to react if a button is clicked or a more complex one to create animations and three-dimensional graphics.

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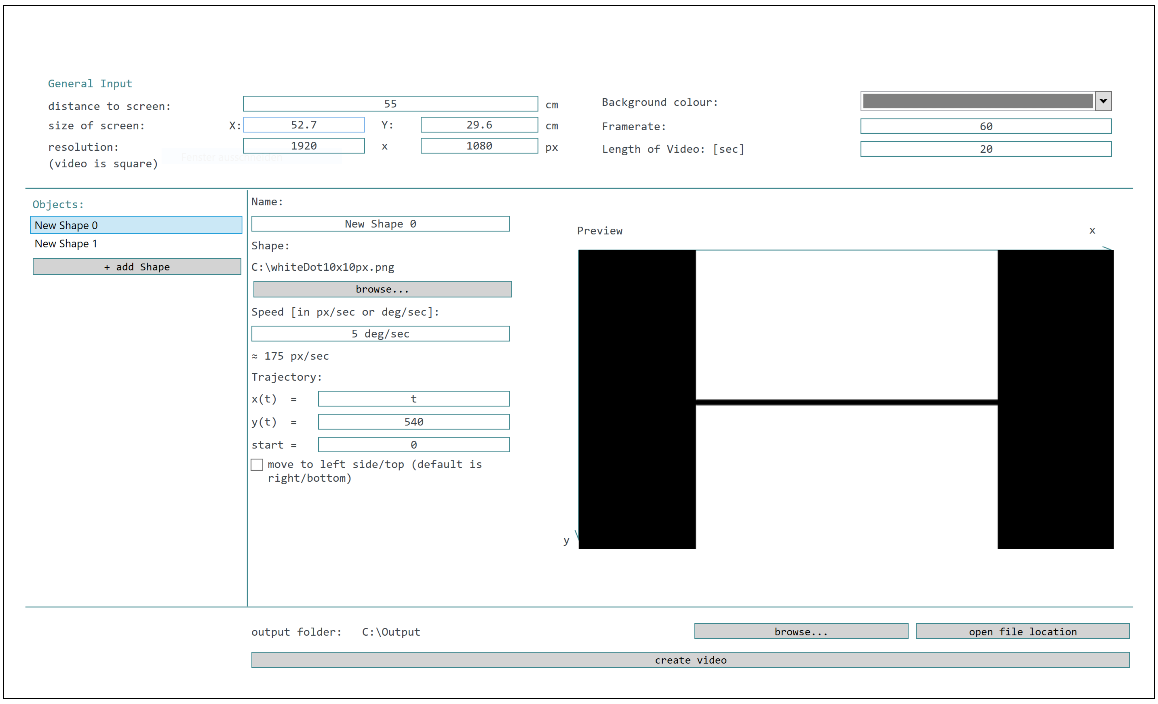
[1] https://visualstudio.microsoft.com/vs/



General Input
distance to screen: 55 cm
size of screen: X: 52.7 Y: 29.6 cm
resolution: 1920 x 1080 px
(video is square)
Background colour:
Framerate: 60
Length of Video: [sec] 20

Objects:
New Shape 0
New Shape 1

Name: New Shape 0
Shape: C:\whiteDot10x10px.png
Speed [in px/sec or deg/sec]: 5 deg/sec
≈ 175 px/sec
Trajectory:
x(t) = t
y(t) = 540
start = 0
☐ move to left side/top (default is right/bottom)

output folder: C:\Output

Figure 3.1: Graphical User Interface of the System.

3.1.2 Libraries

The following section describes the libraries, which were included in the WPF application.

MathNet MathNet[2] is an open source mathematical Library for .NET, written in C# and F#. Christoph Rüegg and Marcus Cuda developed it in 2009. In this project two parts of this Library were used, the first is MathNet Numerics. It includes multiple mathematical functions, like algebra, regression, interpolation and more. The second one is MathNet.Symbolics, it is a mathematical parser, which can parse strings in expressions and evaluate them.

Accord.Video.FFMPEG Accord[3] is a .NET framework, which contains multiple different features and was developed by César Souza in 2009. It contains machine learning algorithms, as well as imaging and video processing tools. The latter was used to export the video, containing the moving object.

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[2] https://www.mathdotnet.com/

[3] http://accord-framework.net/

Extended WPF Toolkit This Framework[4] was developed for WPF by Xceed, is open source and free to use. It contains multiple controls and features, like the ColorPicker, which allows the user to select from a colour palette, specify it through hexadecimal code or choose a special colour in the advanced panel. But there are more controls which can make building a complex application a bit easier.

3.2 Data structure

This section describes the basic structure of the application and how user inputs are stored. To change the properties of the video, the user can specify the following attributes:

- distance between user and screen
- size of screen
- resolution of screen
- background colour of video
- framerate of video
- length of video
- for each shape:
  - name
  - path to figure
  - speed
  - trajectory (x(t) and y(t) as separate equations)
  - starting point
  - side towards which the shape should move
- output folder of video

There are two main objects, which contain the general specifications of the video and the properties of the moving shape.

The former is the Specifications class, which contains multiple attributes, a constructor, get and set methods for each property and an event handler to ensure the user input is updated as soon as one property is changed. Listing 3.1 contains the basic structure of the class, where all attributes are specified and an exemplary method explains how the get and set methods for each property are defined. To use the data binding concept of WPF, this class has to implement the *INotifyPropertyChanged* Interface. There is also an event handler which is thrown as soon as the user leaves the input field.

---

[4] https://xceed.com/xceed-toolkit-plus-for-wpf/

Listing 3.1 Object to save general input

```
class Specifications: INotifyPropertyChanged{
    distanceToScreen:      double;
    sizeOfScreenX:         double;
    sizeOfScreenY:         double;
    resolutionX:           int;
    resolutionY:           int;
    framerate:             double;
    videoLength:           double;
    outputPath:            string;
    event PropertyChanged: PropertyChangedEventHandler;

    //exemplary method
    public double Distance
    {
        get {return distanceToScreen;}
        set
        {
            distanceToScreen = value;
            OnPropertyChanged("Distance");
        }
    }

    ...

    //event handler
    public void OnPropertyChanged(string name){...}

}
```

The general Input is saved in one object, another requirement that is necessary to apply data binding. The first three properties listed above are used to convert the speed from pixels per second to degrees per second (and vice versa) and are stored in the first five attributes of the class (*distanceToScreen*, *sizeOfScreenX*, *sizeOfScreenY*, *resolutionX* and *resolutionY*). The resolution is also used to specify the resolution of the resulting video, however the coordinate system in which the object moves is square and centred in the video. For example, if the resolution of the screen is 1920×1080, then the video would be 1080×1080 with two black rectangles covering the remaining area at both sides of the video. This was important when designing the study, because the distance the shape travels horizontal and vertical must be the same to compare both conditions. To choose the background colour of the video the user can either use a predefined colour or switch to the advanced tab where a hexadecimal code or RGBA values can be entered. When no value is selected, the background is white. Next, the framerate can be specified and is saved in the property *framerate*. The last field at the top of the window is the length of the video, which is in seconds and stored in the attribute *videoLength*. Finally, the output path that defines the location at which the video is saved must be specified by clicking the “browse” button at the bottom of the window (the string containing the file path is saved in *outputPath*).

Listing 3.2 Data structure of shapes

```
class Shape: INotifyPropertyChanged{
    itemName:       string;
    form:           string;
    speed:          double;
    speedInDegrees: string;
    trajectoryX:    string;
    trajectoryY:    string;
    startingpoint:  int;
    side:           bool;
    preview:        string;
    points:         float[,];
    event PropertyChanged: PropertyChangedEventHandler;

    //exemplary method
    public double Speed{
        get {return speed;}
        set{
            speed = value;
            OnPropertyChanged("Speed")
       }
    }

    ...

    //event handler
    public void OnPropertyChanged(string name){...}

}
```

The main objects of this application are shapes, they are saved in an Observerable Collection and the user can add new ones by pressing a button. This is where the user input of the GUI is saved and later used to calculate the position of the object in every frame.

Since the concept of data binding is used, the Shape class also contains get and set methods for every attribute, as well as a constructor and an event handler. The general structure of this class can be seen in Listing 3.2. This contains all attributes and one exemplary method that handles the event when the speed is changed. As soon as the user leaves the input field by for instance clicking somewhere else, an event is thrown and the attribute of the shape is updated immediately. To catch the right event, a string containing the name of the changed attribute is passed to the event handler.

Each shape has a name, which at first is “New Shape” and a consecutive number, but it can be changed to any string containing only letters and numbers. This property is stored in the first attribute of the shape class, the *itemName*. The next input is the form of the shape, which is stored in the attribute *form*. This is specified as an image the user must choose and the path is displayed on top of a button, which allows the user to open the windows file explorer. This path is later used to get the image and draw it on top of the background at the calculated coordinates. Next, a speed must be specified, here the user can choose between entering it in pixel or degrees per second by simply typing the unit deg/sec or px/sec after the numeric value. It automatically is displayed in the corresponding unit right beneath the input field and the program later uses the pixel per second value, but both are stored in the object (*speed* and *speedInDegrees*). The Trajectory, which the object should follow later is defined by two separate parametric equations, saved in the attributes *trajectoryX* and *trajectoryY*. These two equations can contain numbers, the basic trigonometric functions (sin, cos, tan) and the standard mathematical operators $(+, -, /, *, \hat{})$. Both functions depend on the parameter t. There is also the option to enter a specific starting point in the system of coordinates (stored in *startingpoint*). If the shape should start at the end or beginning of the screen, this input field should be zero. It is actually just one value along the trajectory of the shape, for example if the shape should start at the centre and the video is 1080×1080, then the number 540 must be entered. If the trajectory of the shape is shifted to the bottom, for instance $x(t) = 540$ and $y(t) = t + 270$, then the shape would start to move at $(540, 270)$. The last property that can be changed is the direction in which the object should move. This is a simple checkbox, if it is checked the shape moves to the left side or top (according to the equation that has been entered). If not, then the shape moves to the default side (right or bottom) and the attribute *side* is set to false.

The shape class also contains the path to the preview image, which gets updates as soon as one property changes and is shown at the right side of the window. In addition, a two-dimensional array, which holds the calculated positions where the image of the shape should be drawn at each frame is stored in the attribute *points*.

To ensure the stability of the program validation rules are implemented, these can be used when data binding is applied to the control. Before the value of the objects is updated, the rule is evaluated and if it throws an error this is shown to the user. This makes sure that invalid data is not saved and crashes the application when it will be further processed.

3.3 Calculation

This section explains how the position of the shape in each frame is calculated.

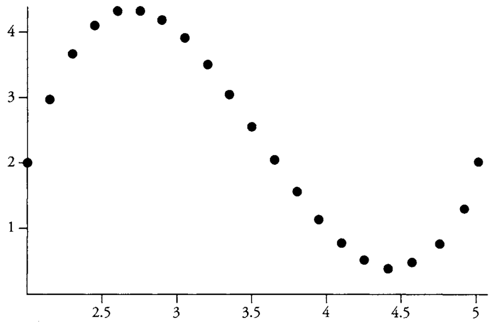


Figure 3.2: Example of points produced by equal increments of an interpolating parameter for a typical cubic curve [Par02, p. 69].

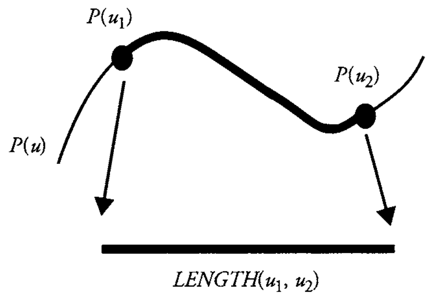


Figure 3.3: Example for arc length between two points [Par02, p. 72].

The speed of the object travelling along a curve should be controlled, to make sure it is constant at every point. In kinematics, the trajectory of the moving object is mostly specified as parametric equations. These kinds of equations are dependent on one or more parameters, often called t, because the coordinates depend on time. They are expressed as two separate functions $x = f(t)$ and $y = g(t)$ and can be integrated and differentiated term wise [Par02, p. 453]. Parametrizing the curve by arc length is important, when an animated object is supposed to move at a constant speed. This means, stepping along a curve in equal increments does not necessarily result in a constant speed (see Figure 3.2). There are multiple approaches to re-parametrise the curve by arc length.

One aspect for choosing the approach that fits the most was, that the trajectory and therefore the parametric equations, which must be parametrized, was given beforehand and thus the calculation could be performed as a pre-processing step. As a brief summary before the computation is explained in detail, at first the curve needs to be parametrized by arc length and afterwards some kind of reparameterization must be performed to establish a table containing the arc lengths and corresponding parametric values. Parent [Par02, p. 69-76] explains what the two main problems are and how they can be solved. The first one being the need to find the length of a given interval on the curve and the second one describes the requirement to find the corresponding point at the curve for a given starting point and arc length. Figure 3.3 shows a visualisation of the first problem, the arc length between two points (u_1 and u_2) must be calculated. In practice, these problems do not have an analytical solution so numerical techniques must be used [Par02, p. 72]. To solve the first problem, the arc length can be computed according to this formula [Par02, p. 72 f.], where u_i are positions along the curve:

$$\begin{gathered} s = \int_{u_1}^{u_2} |dP/du| du \\ |dP/du| = \sqrt{(dx(u)/du)^2 + (dy(u)/du)^2 + (dz(u)/du)^2} \end{gathered} \tag{3.1}$$

Equation (3.1) performs two steps, the first being the calculation of the arc length by taking the square root of the squared deviation of the parametric equations and then integrating the result for the entire equation. This results in a new formula, which can be reparametrized and then evaluated at the desired point. In practice, as explained above, a numerical integration is used, for example Simpsons method [Spi, p. 85]:

$$\int_a^b f(x)\,dx \approx \frac{\Delta x}{3}\{y_0 + 4y_1 + 2y_2 + 4y_3 + 2y_4 + 4y_5 + ... + 2y_{n-2} + 4y_{n-1} + 2y_n\} \tag{3.2}$$

So practically, this integral can be computed for multiple points along the curve and then a tabular containing the parametric value and the corresponding arc length can be created. It is important to super sample the curve to reduce errors [Par02, p. 76]. After determining how fast the object should move per frame, this value can be used to search the table for the corresponding arc length, and then the parametric equations must be evaluated at this point. Since the arc length is a monotonous increasing function, a binary search is efficient and should be used. Obviously, the parametric value might not be in the table, so the nearest value must be returned by the binary search. This explains why super sampling the curve is important to reduce errors.

For this application, it was not required, but there is a possibility to use the same approach and extend it so the object can for example accelerate or in general move along a non-linear velocity curve. Plus, it can be calculated in a two or three-dimensional space, for this application the former one was used.

3.4 Use case

In this section a use case for the software is described. The goal is to create one video containing two moving shapes. At first, the general input must be entered. As Figure 3.1 on page 20 shows, the distance, size and resolution of the screen must be determined. For this use case the values are the same as in Figure 3.1. Next, the background colour for the video is set to grey by using the drop-down menu at the upper right corner. Right beneath this, the frame rate needs to be entered, which is 60 to ensure a smooth moving object. After this, the length of the video is set to 20 seconds. By doing the above steps, typing in the general input is finished and the specific attributes of the shapes can now be entered. At first, a new shape has to be added to the objects list by pressing the "+ add Shape" button on the left. Then, the name of the shape could be changed, but this is optional. To select a picture containing the object, the "browse" button beneath the name must be pressed. There is a pop-up containing the windows file explorer which allows the user to choose the right picture. Afterwards, any speed like "5 deg/sec" must be entered in the corresponding input field and is displayed in px/sec right beneath it. It is possible to enter the velocity in px/sec, as well. Then the path on which the object should later move must be specified. To ensure the target moves horizontally in the centre of the screen, x(t) is set to t and y(t) is according to the screen size, 540. As the shape should start at the left side, the starting point is 0 and the check box remains unchecked. When the preview is updated, the path can be checked. To add another shape, the "+ add Shape" button must be pressed again. After this, all input fields containing the new shape must be filled out once more. In short, the name can stay unchanged (New Shape 1), then a picture needs to be defined. The speed can be entered in a unit of choice, since these shapes are completely independent and thereafter both equations of the trajectory must be entered. This time the shape will move downwards, beginning at the centre of the screen, so x(t) is 540, y(t) is just t and the starting point is 540, as well. To ensure the object moves to the bottom, the checkbox needs to be checked and the preview shows the path once more. This process can be repeated as often as needed. To save the video, the output folder must be chosen by pressing the "browse" button in the lower right corner. After clicking the "create video" button, the result can be viewed by clicking the "open file location" button.

4 Study

The following chapter describes the data collection study. This includes the design of the study, facts about the used apparatus, the procedure of conducting the study and information about the participants at the end.

4.1 Design

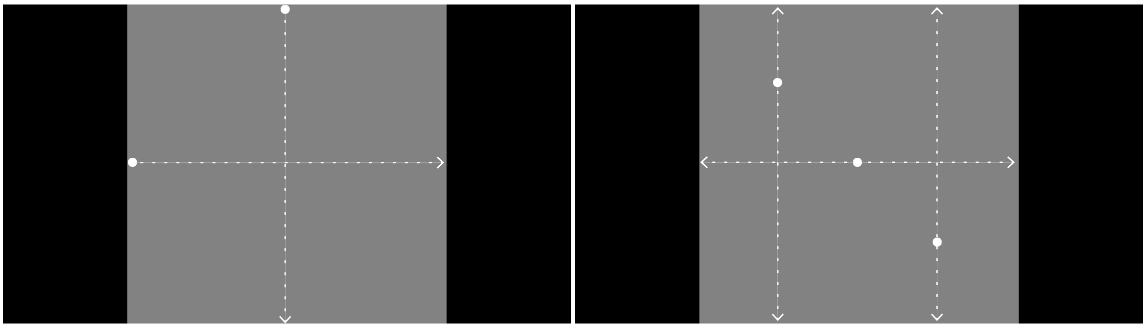
Our main goal was to determine, how different factors influence the smooth pursuit eye movement. Therefore, we tested various factors by showing the participant short video clips containing moving shapes. These shapes were white filled out circles, which had a diameter of 42 pixels. The background of the video was grey (#FF808080) to avoid eye exhaustion and to prevent the participant from noticing a flickering due to a high contrast (e.g. a black background) after some time, as well [KHW+18]. The order of the video clips was randomised, and every condition was shown twice. As a summary, Table 4.1 shows all independent variables.

The target moved at four different speeds (5 °/s, 10 °/s, 15 °/s and 20 °/s), leading to our first four conditions (TargetVelocity). The paths illustrated in Figure 4.1 represent one exemplary video for the condition NumberOfDistractors. The dashed lines represent the path of the target and are not visible in the actual video.

target velocity	**axis**	**number of distractors**	**target velocity**	**axis**	**number of distractors**
5 °/s	horizontal	0	15 °/s	horizontal	0
		1			1
		2			2
	vertical	0		vertical	0
		1			1
		2			2
10 °/s	horizontal	0	20 °/s	horizontal	0
		1			1
		2			2
	vertical	0		vertical	0
		1			1
		2			2

Table 4.1: All independent variables of the study.

(a) Picture of direction in which target will move. **(b)** First frame of every video clip.



(c) First frame when distractor one starts to move. **(d)** First frame of video containing two distractors.

Figure 4.1: Diverse frames of the video clips for different conditions. The dashed arrows represent the path the objects moved during the video.

Furthermore, one additional goal was to find out, if there is a difference between horizontal and vertical moving objects (Axis). So, we created two different conditions, one where the target moves from left to right or vice versa (horizontal) and the second one is the vertical version, where the target moves from top to bottom or upwards (vertical). The target always started at the centre of the screen and moved to a random direction. To avoid an error at the beginning of the smooth pursuit eye movement, we displayed a picture showing the target and an arrow, which pointed in the direction the target later moves to, so the participant would start the movement correctly right away (see Figure 4.1a). In general, the target moved in a cycle. It started at the centre of the screen $(960, 540)$ (see Figure 4.1b), then moved to the end of the video (here the video was 1080×1080 px), turned around and followed the path to the other side of the clip, then turned again and stopped at the centre once more. This cycle was repeated three times for every video which resulted in different lengths (5 °/s: 36 s, 10 °/s: 18 s, 15 °/s: 12 s and 20 °/s: 9 s). Of course, the participant did not notice this repetition, the target moved steady without actually stopping until the video was finished.

In addition, we wanted to test the influence of distractors on smooth pursuits (NumberOfDistractors). For that reason, there were three more conditions. The first being a baseline condition where the participant had to follow only one target to test whether he is capable of doing a smooth pursuit eye movement (number of distractors: 0). The second one contained one additional shape, which moved at the same speed, as the one the participant had to follow (number of distractors: 1). It started at the centre of the screen, at the top or left side $((960, 0), (0, 540))$, after the target had reached one side of the video. Figure 4.1c shows the path of the distractor, which resulted in two collisions between the target and the distractor per cycle and consequently there were six collision in every video clip.

The last condition included two distractors, which moved at the same speed as the target as well (number of distractors: 2). As shown in Figure 4.1d, both distractors started equally far away from the target. The left distractor started to move downwards, whereas the right one moved upwards. This leads to one collision with each distractor per cycle and six collisions in the video clip.

4.2 Apparatus

This section describes the setup we used to conduct the study. At first, the hardware will be specified, followed by a short paragraph about the room setup. The last part contains the software we used to run the study.

4.2.1 Hardware

The hardware of this study consisted of two main parts, the Tobii Pro Spectrum[1] eye tracker and the computer running the software.

Tobii Pro Spectrum For our setup, we used the Tobii Pro Spectrum eye tracker, which is a screen-based eye tracker. This eye tracker is a high performance one and fairly new to the market. Researchers who need very precise data therefore mostly use it. It consists of the eye tracker unit and a supplied removable monitor on top. We used the maximum of 1200 Hz sampling frequency, but the eye tracker is capable of sampling at different frequencies ranging from 60 Hz to 1200 Hz. It can do both, binocular bright and dark pupil tracking and measure the eye gaze position in addition to the pupil diameter. The maximum gaze angle is 30° at an operating distance between 55 cm to 75 cm. We used the attached 23.8'' monitor with a resolution of 1920 × 1080 px.

Computer The computer was used to run the Tobi Pro Lab Software, it was running Windows 10 (64 bit) and consisted of an Intel i7-7700K CPU, 32 GB of Ram and a NVIDIA GeForce GTX 1070. It was connected to the eye tracker unit and two different displays, one to show the videos to the participants on top of the eye tracker unit and a second one to control the study.

4.2.2 Room setup

The study was conducted in a laboratory. It was a rather big room with enough space for the participant to feel comfortable. In order to avoid the inference factor of the sunlight, all windows were closed with a blind. To ensure a great performance of the eye tracker, the lights in the room were also turned off, besides the most distant one at the other side of the room so it was still bright enough to see everything. The participant was seated next to the person conducting the study. They sat on a height-adjustable chair to increase the comfort, as the headrest kept the head for all participants at the same height. This was attached to the table, 55 cm from the eye tracker. The eye tracker was positioned above the table, so that the participant's head was centred in front of

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[1] https://www.tobiipro.com/product-listing/tobii-pro-spectrum/

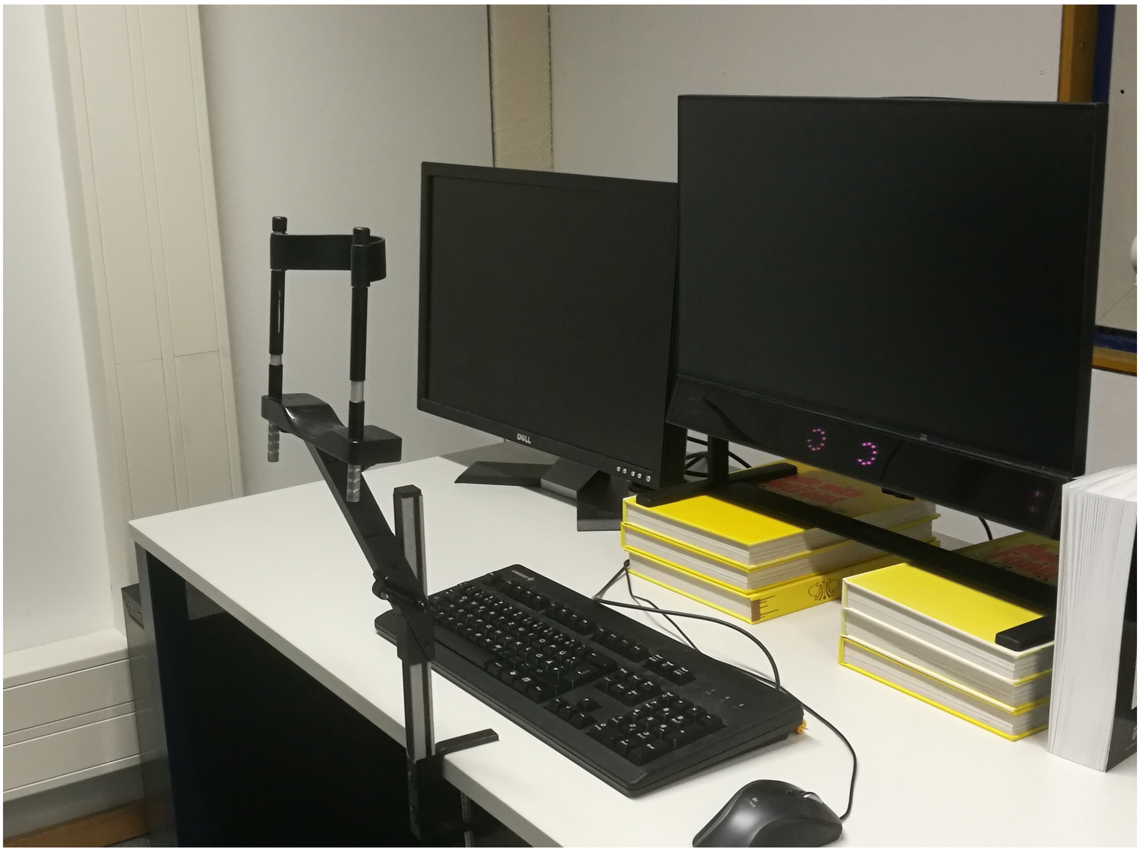

Figure 4.2: Setup of the study with the headrest and eye tracker.

the attached display where the videos were shown. Next to this one, there was one display for the person conducting the study as well, to start the software and check if everything is fine by using the live view of the Tobii Pro Lab Software[2]. It was turned to the left to ensure the participant was not confused or irritated by the live view. The setup is shown in Figure 4.2.

4.2.3 Software

We used the software described in Chapter 3 to create the video clips that were shown to the participant. In addition, we used the Tobii Pro Lab Software to create a project that contains all conditions. With this software, we created a design of our experiment so that we could record the setup with the eye tracker. At first, we designed one timeline, which contained the calibration and a group containing all video stimuli. There is an option to change the properties of the calibration stimuli, so we decided to use a grey background (#FF808080), and white points so that it would be as similar to the video clips as possible. This may affect the quality of the calibration and therefore the overall tracking quality.

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[2] https://www.tobiipro.com/produkte/tobii-pro-lab/

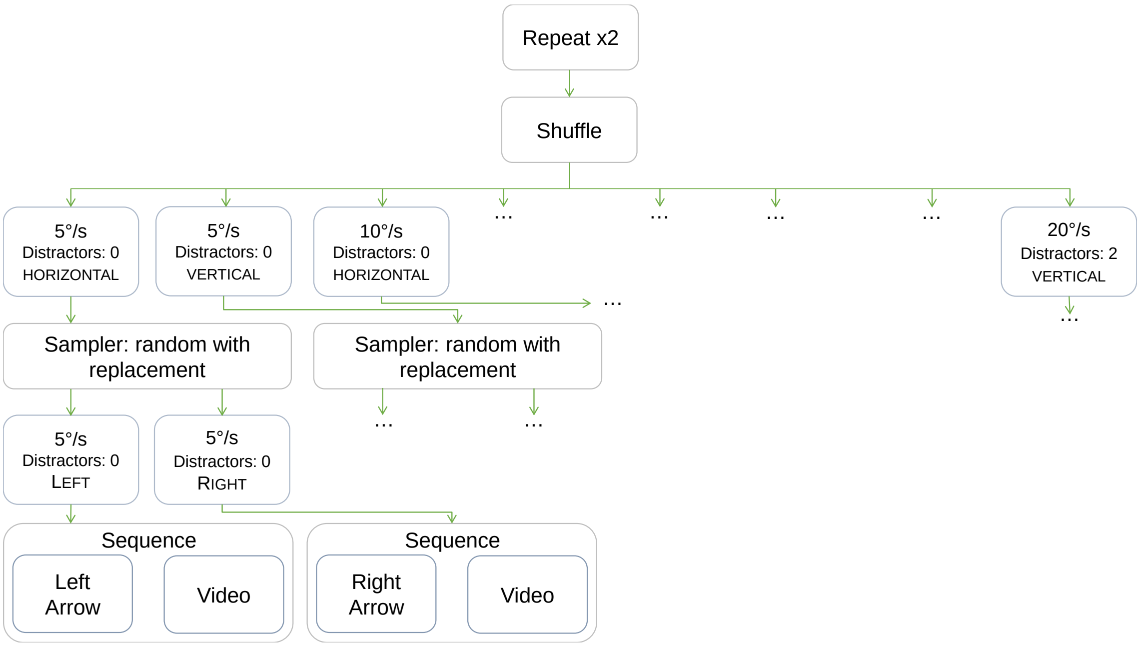


Figure 4.3: Design of the study created with the Tobii Pro Lab Software.

Figure 4.3 shows the structure of the design. The first and only group in the timeline was a repeater to ensure every condition was displayed twice to the participant. In this group, there was a shuffler, which randomised the order of the conditions. Again, this group contained multiple groups. These were the actual conditions, which results in a total of 24 groups. Each member of this group contained a sampler, which takes one of the subgroups, displays it and puts it back in so it can be picked again the next time. This randomises the direction in which the target moves. Both groups, which could be picked by the sampler, contain a sequence of the picture, which shows in which direction the target will move and the according video. This ensures that the right picture will be shown every time a new stimulus is chosen. An example of how this looks like for the first condition is illustrated in Figure 4.3, the other ones are built in the same way.

4.3 Procedure

After welcoming the participants, they had to sign a consent form, which contains legal information and explains to the participants, for example what will happen with the recorded data and it included the statement, that the participant can take a break at any time during the study. After that, they had to fill out a demographics questionnaire. We collected standard data, like age, gender, eye dominance and since this might be important later, we wanted to know if they wore glasses or contact lenses. To determine the dominant eye, we used the Porta [Del99] test. We asked the participants to hold their thumb over a distant target with both eyes open. Then they should close each eye separately, and for whichever opened eye the thumb was still over the target was the dominant one.

We then explained the procedure of the Study, which consisted of 24 conditions. We told the participant that we first need to calibrate the eye tracker. Therefore, we used the nine-point calibration and repeated this until the accuracy was good. We also told the participant to focus on the centre of the moving dot, because this can optimise the calibration process. Before calibrating, we also explained that they would at first see a picture which shows the direction in which the target will move. We asked them to press space on the keyboard on the table in front of them when they understood in which direction the point would move and they were ready to watch the video clip.

After approximately 20 minutes, the participant finished watching all animation clips and was rewarded with 5 Euros. We thanked them and answered previous questions which could not be addressed before to avoid an influence on the data.

4.4 Participants

We invited people from the university. Altogether, we had 24 participants, which were between 15 and 30 years old (M = 22.54, SD=3.26). There were 16 male and 8 female participants. Overall, 4 participants wore glasses and two wore contact lenses, what results in 18 remaining participants without any visual aid. The eye dominance was right for 17 and left for 8 participants, one stated to have no dominant eye.

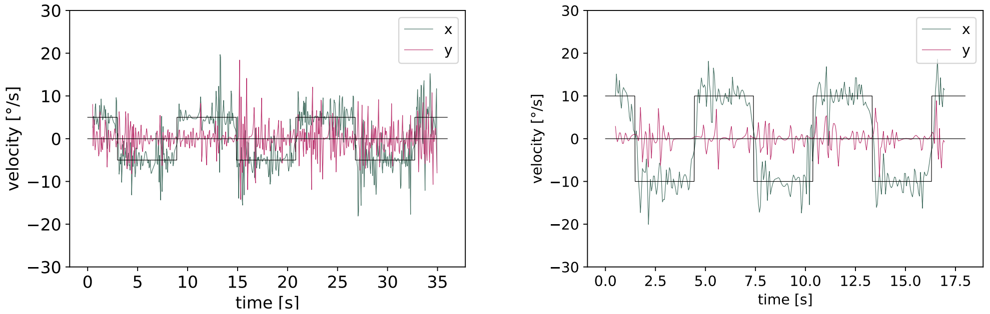
5 Results

This chapter describes the results of the study, which can be separated in two sections, the first being the movement analysis and the last one is about calculations using areas of interest (AOI). The latter section contains the dwell time of all shapes and transitions between target and distractors. The independent variables of the study are listed in Table 4.1 on page 27.

5.1 Movement Analysis

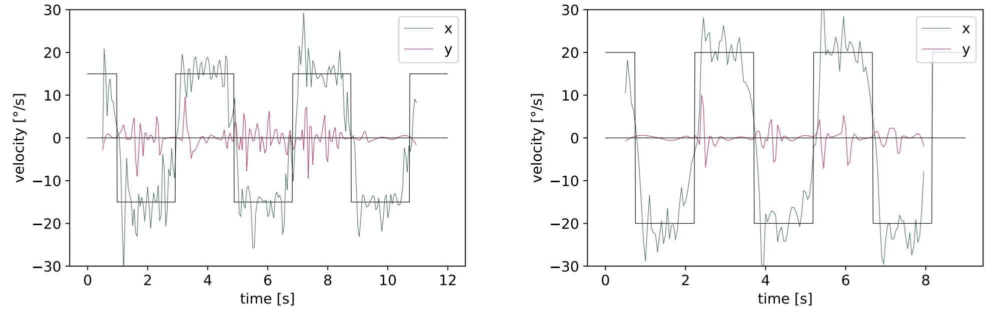
To analyse the eye movement of the participants, this section contains the velocity and spatial position of the gaze data compared to the target.

5.1.1 Velocity



(a) target velocity: 5°/s

(b) target velocity: 10°/s



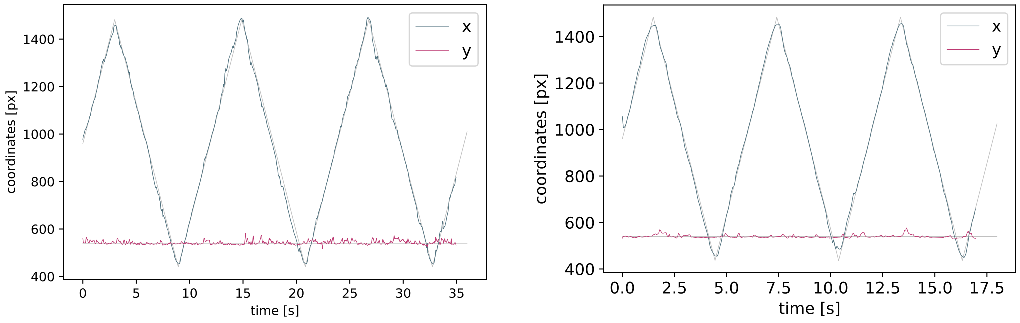
(c) target velocity: 15°/s

(d) target velocity: 20°/s

Figure 5.1: Comparison of the mean gaze velocity of all participants with the target velocity. The axis on which the target moved was horizontal with no distractor. Each plot shows one target velocity.

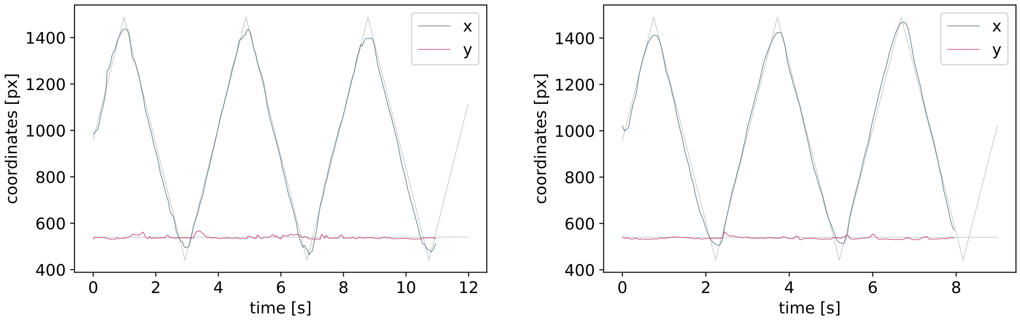
The velocity is a good starting point to check if participants were able to follow the target. We calculated the mean for each participant at first, as they viewed each condition twice. After this, we calculated the mean velocity over all participants. Besides averaging the velocity, we did not perform any further filtering. We divided the velocity in x and y direction, because this leads to exact results on how the participants were able to follow the target. Figure 5.1 on the preceding page shows the results for one condition, divided into one plot for each velocity.

Here, a black line represents the target velocity. The eye velocity in x direction is a green one, and a red line shows the velocity in y direction. These plots show that the noise added by the velocity in y direction decreases with a higher target speed, but the participants were able to follow the target. Additionally, there is more noise for a target velocity of 5 °/s, what implies that it was too slow for the participants. They were not able to maintain the exact target velocity, but compared to the faster target velocity of 20 °/s, the mean gaze velocity does not contain as much variance. Besides the added noise for the slower target velocity, the participants were able to follow the moving target until the end of the video. As the plots for the faster target velocities show, the target reached the centre of the screen before the gaze of the participants. All plots of the velocity are shown in Appendix A.1 on page 51.



(a) target velocity: 5°/s

(b) target velocity: 10°/s



(c) target velocity: 15°/s

(d) target velocity: 20°/s

Figure 5.2: Plots containing the spatial position of the target compared to the average gaze position of all participants separated by the target speed. The axis was horizontal and there was no distractor.

5.1.2 Position

We plotted the mean position of the gaze point of all participants with the actual position of the target, as well. Figure 5.2 on the facing page shows the same conditions as Figure 5.1 on page 33, but here the position is shown instead of the velocity. It is separated in x and y coordinates, with the blue line showing the x coordinates of the mean gaze point over all participants and the red line being the same for the y coordinates. The position of the target is shown in grey, and the time is plotted on the x axis of all figures. The grey dots represent the intersection between the target and any distractor, which are not visible here, since there is no distractor present.

It appears that the participants had less time to follow the target, because the maximum of the position is not completely reached with an increasing speed. Comparing Figure 5.2a and Figure 5.2d for instance shows that the participants no longer looked all the way to the edge of the video. Furthermore, with an increasing speed, there is a distance between the end point of the target and the gaze position. As described above in the velocity section, when the target reached the centre of the

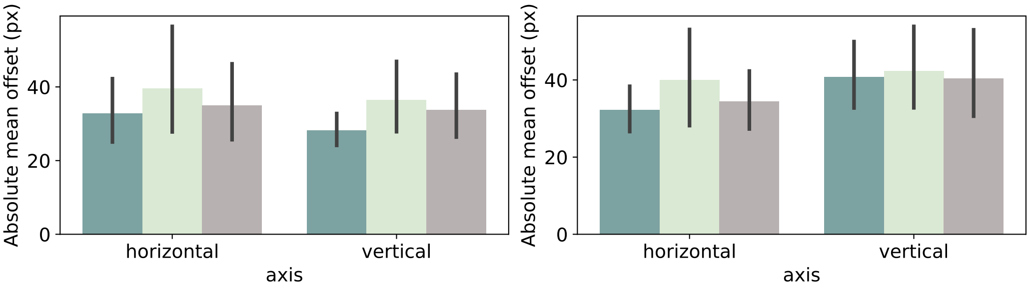
target velocity	**number of distractors**	**axis**	**distance**	
			M	SD
5	0	horizontal	15.96	21.41
5	0	vertical	10.76	08.19
5	1	horizontal	21.51	32.73
5	1	vertical	17.70	18.11
5	2	horizontal	17.38	22.33
5	2	vertical	15.54	16.21
10	0	horizontal	14.56	12.08
10	0	vertical	22.02	19.24
10	1	horizontal	21.65	28.12
10	1	vertical	23.41	24.11
10	2	horizontal	16.84	17.44
10	2	vertical	21.65	25.83
15	0	horizontal	27.95	34.32
15	0	vertical	41.59	34.11
15	1	horizontal	21.42	23.86
15	1	vertical	31.90	25.47
15	2	horizontal	18.61	16.71
15	2	vertical	27.01	31.52
20	0	horizontal	28.71	34.09
20	0	vertical	37.03	26.14
20	1	horizontal	95.33	37.05
20	1	vertical	82.52	13.31
20	2	horizontal	21.33	18.85
20	2	vertical	36.83	36.01

Table 5.1: Mean M and standard deviation SD for the average distance between the gaze point and target position per condition in pixels.

screen and the video stopped, the gaze of the participant was behind the target position. This effect increased with a higher target speed. Again, all plots are shown in Appendix A.3 on page 66.

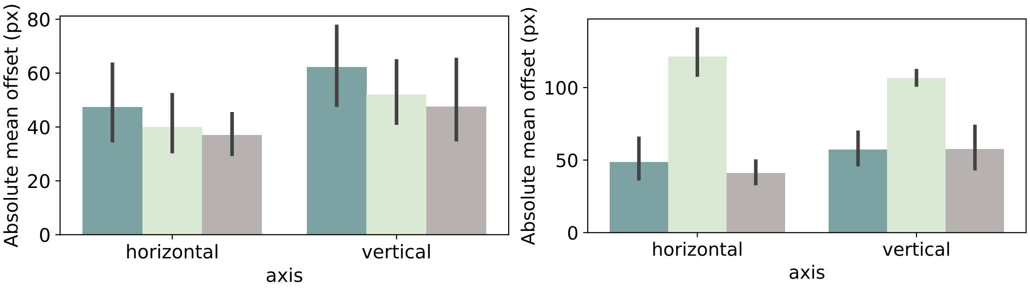
Table 5.1 on the previous page shows the exact results for the offset between the gaze and target position, containing the mean and standard deviation. We performed one three-way ANOVA to check, if any of the independent variables (velocity, number of distractors and axis) have an influence on the distance between the gaze point and the position of the target. The results show that the velocity has a significant effect on the dependent variable ($F = 11.125$, $p < 0.01$), but no other independent variables have an influence. Additionally, we performed post hoc tests, using a pairwise t-test with Bonferroni correction applied. There was a significant difference for 20 °/s and 5 °/s ($p < 0.01$) and for 20 °/s and 10 °/s ($p = 0.0198$). Taking this into account, we can reject the null hypothesis: "The target velocity has no influence on the average distance between the gaze point and the position of the target."

Figure 5.3 shows a graphical representation of the statistical tests. Here, the mean offset between the gaze point and position of the target (using the closest point of the edge of the circle) and the confidence interval of 95 % are shown. We divided the conditions in four plots, one for each target velocity. In each plot there are two areas containing the different axis and all numbers of distractors (see Figure 5.3e for the legend). These plots show an increasing offset for faster target velocities. But there is little difference between the mean values when looking at the two remaining variables over all target velocities, which supports the findings described above, they do not have a significant effect on the offset.



(a) target velocity: 5 °/s

(b) target velocity: 10 °/s



(c) target velocity: 15 °/s

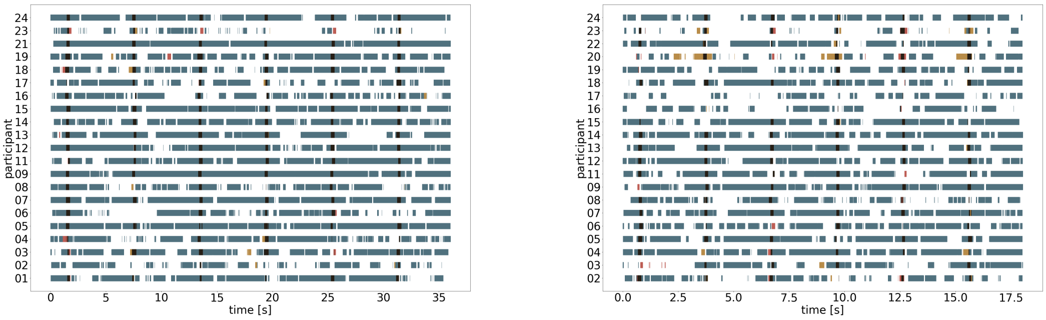
(d) target velocity: 20 °/s

(e) Number of distractors

Figure 5.3: Bar plots containing the mean and confidence interval (95%) of the offset between gaze point and position of the target.

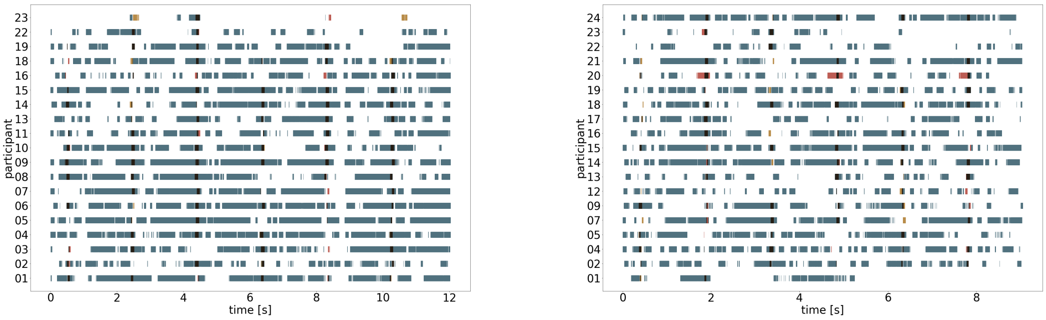
5.2 Area of Interest

To evaluate the raw data, we implemented an AOI hit count. This script calculates if the distance between the point the participant looked at and the centre of the moving target is smaller than the radius plus a threshold. Or to put it another way, it checked, if the gaze point was inside the circular target, extended to a larger radius. This was calculated for each shape separately and we did not use the data of the intersection, as the participant looked at both shapes at the same time, it is not possible to tell at which one. Since every condition was recorded multiple times for each participant, first we calculated at the mean time for each condition and participant separately. The last step was to calculate the mean over all participants, as described in the former section.



(a) velocity: 5 °/s

(b) velocity: 10 °/s



(c) velocity: 15 °/s

(d) velocity: 20 °/s

(e) Legend for the plots above.

Figure 5.4: Illustration of AOI hit for different velocities. The axis was vertical (target moved to the bottom) and there were two distractors.

5.2.1 Dwell time

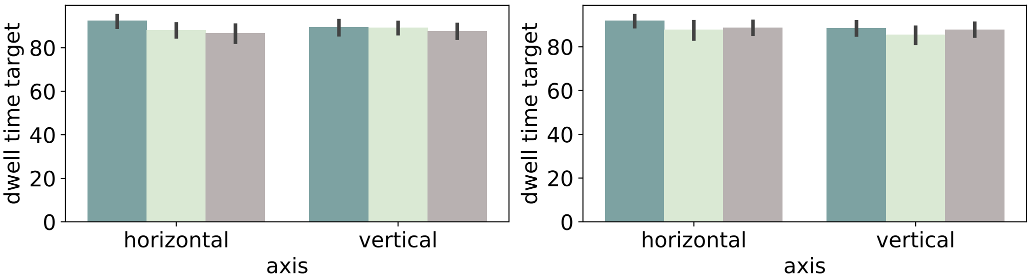
We plotted the different AOIs the participant looked at; these plots are shown in Figure 5.4. If the participant looked at the target, this time interval is marked blue, when one distractor was present, this is marked red and for the last condition, the second distractor is brown. The black part is where the participant looked at more than one shape and white if he did not look at any shape. As the target moved randomly to the left and right side, not every participant watched every video and therefore, the plots do not contain every subject. These illustrations show that the participants were able to follow the shape better for slower velocities. This is clearly shown in Figure 5.4d, as there is an increase in white areas compared to the slow velocity in Figure 5.4a. Furthermore, the participants did not look at the distractors often, and most of the time they looked at them shortly before the intersection with the target. All plots are shown in Appendix A.4 on page 79.

As described above, we calculated the dwell time for each shape and these results are shown in Table 5.2. To measure, how long participants were able to follow the target correctly, we used the total dwell time of the target in milliseconds and calculated the mean over all participants. We then determined the percentage of this in relation to the total time of the video, since not all conditions

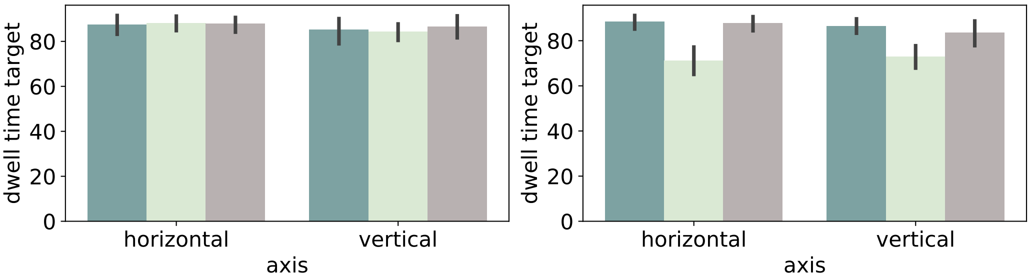
			threshold 10 px				**threshold 20 px**			
target velocity	**number of distractors**	**axis**	**target**		**Σ distractors**		**target**		**Σ distractors**	
			M	SD	M	SD	M	SD	M	SD
5	0	horizontal	87.76	09.19	00.00	00.00	92.38	07.07	00.00	00.00
5	0	vertical	84.21	10.59	00.00	00.00	89.42	07.88	00.00	00.00
5	1	horizontal	82.12	13.55	17.70	21.86	88.02	07.69	12.93	19.10
5	1	vertical	82.40	10.46	14.10	21.32	89.12	05.65	15.83	23.00
5	2	horizontal	81.16	14.79	17.30	23.33	86.67	10.03	11.61	18.20
5	2	vertical	81.47	10.86	20.93	27.95	87.47	08.23	15.82	22.82
10	0	horizontal	84.93	10.93	00.00	00.00	91.78	06.46	00.00	00.00
10	0	vertical	81.74	08.92	00.00	00.00	88.46	07.60	00.00	00.00
10	1	horizontal	83.69	11.97	19.16	28.31	87.87	10.01	12.89	21.60
10	1	vertical	80.82	12.37	38.77	26.86	85.38	09.32	27.48	29.50
10	2	horizontal	84.16	10.27	14.27	24.71	88.65	07.66	05.96	13.82
10	2	vertical	82.81	10.86	26.54	33.91	87.78	07.37	30.01	31.29
15	0	horizontal	79.48	14.74	00.00	00.00	87.57	10.56	00.00	00.00
15	0	vertical	81.68	12.02	00.00	00.00	85.26	13.69	00.00	00.00
15	1	horizontal	80.81	13.10	21.06	20.71	88.23	07.96	11.41	15.60
15	1	vertical	79.70	11.90	30.30	21.09	84.38	09.33	20.11	21.07
15	2	horizontal	81.88	10.77	23.48	31.31	87.88	08.08	12.74	18.13
15	2	vertical	83.30	12.17	24.95	29.15	86.69	12.40	31.90	36.85
20	0	horizontal	84.73	12.02	00.00	00.00	88.41	07.71	00.00	00.00
20	0	vertical	82.13	10.00	00.00	00.00	86.54	08.13	00.00	00.00
20	1	horizontal	66.09	20.36	06.68	15.67	71.27	14.84	07.72	13.47
20	1	vertical	69.36	17.09	02.33	05.94	72.93	12.24	07.25	14.65
20	2	horizontal	81.55	11.47	32.67	29.41	87.82	07.60	21.03	27.95
20	2	vertical	81.05	14.76	36.12	30.72	83.52	13.53	29.40	33.44

Table 5.2: Mean dwell time M and standard deviation SD as a percentage rounded to two decimal figures.

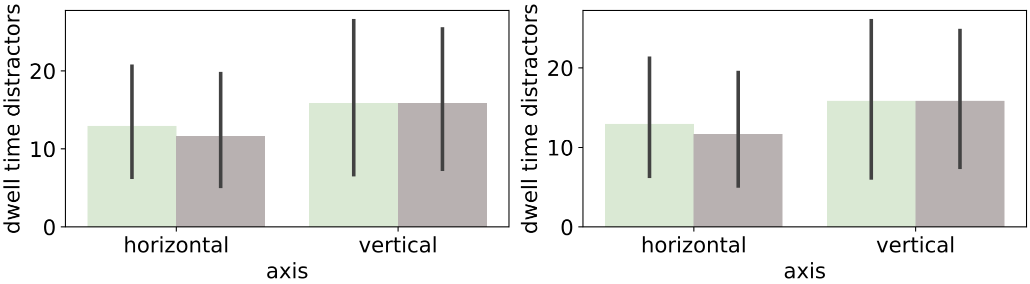
were the same length. This can be repeated the same way for the dwell time of the distractors. We used the sum over all distractors, because we needed to compare conditions with different numbers of distractors.



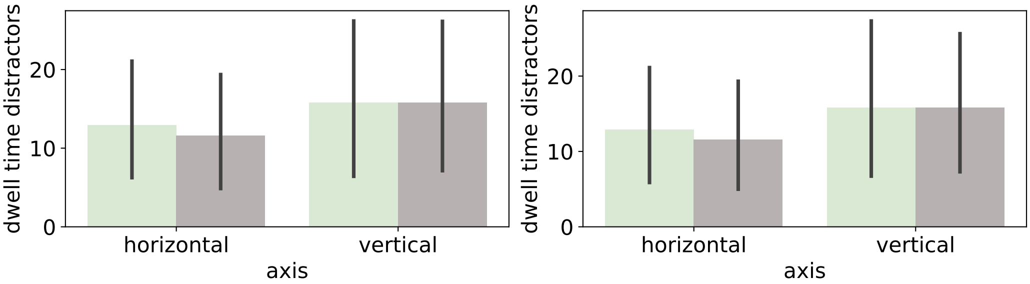
(a) target velocity: 5 °/s, threshold: 20 px **(b)** target velocity: 10 °/s, threshold: 20 px



(c) target velocity: 15 °/s, threshold: 20 px **(d)** target velocity: 20 °/s, threshold: 20 px



(e) target velocity: 5 °/s, threshold: 20 px **(f)** target velocity: 10 °/s, threshold: 20 px



(g) target velocity: 15 °/s, threshold: 20 px **(h)** target velocity: 20 °/s, threshold: 20 px

(i) Number of distractors

Figure 5.5: Bar plots containing the mean and confidence interval of the dwell time of the target and distractors for a threshold of 20 px and all conditions.

We performed multiple three-way ANOVAs to check if any of the independent variables have an influence on the time the participants looked at the different shapes. The results indicate that the velocity has a significant effect on the dwell time of the target. We did this for a threshold (regarding the radius of the AOI) of 10 px ($F = 4.928,\ p = 0.0412$) and 20 px ($F = 7.432,\ p = 0.0149$). Additionally, we performed post hoc tests, using the same method as mentioned above. This resulted in no significant value for the first ANOVA, but there is a significant difference for the target velocity of 20 °/s and 5 °/s ($p = 0.048$), as well as 20 °s and 10 °/s ($p = 0.078$) for the bigger threshold. This means that we can reject two null hypotheses: "The target velocity has no significant influence on the dwell time of the target, using a threshold of 10 px" and "The target velocity has no significant effect on the dwell time of the target, using a threshold of 20 px". Additionally, these results are illustrated in Figure 5.5.

There are also significant effects on the dwell time of the sum of all distractors. Again, we performed two three-way ANOVAs for both thresholds, using a significance level of 90 %. The first one (threshold = 10 px) indicates that there is a significant effect of the number of distractors on the dwell time of the distractors ($F = 3.567,\ p = 0.0956$). We used the same post hoc tests as described above, but they did not result in any significant differences. The second ANOVA (threshold = 20 px) found a significant effect of the number of distractors, as well ($F = 5.640,\ p = 0.04491$), but there was also no significant difference when performing the post hoc test. As a contrast to the first ANOVA, we found a significant effect of the axis ($F = 11.466,\ p = 0.00955$) and this time there was a significant difference between the vertical and horizontal axis, determined by the post hoc test ($p = 0.011$). In this case, we can reject the following null hypotheses: "The number of distractors has no influence on the dwell time of the distractors, using a threshold of 10 px", "The number of distractors has no influence on the dwell time of the distractors, using a threshold of 20 px" and "The axis has no influence on the dwell time of the distractors, using a threshold of 20 px".

See Figure 5.5 for a plot of these results for a threshold of 20 px. For the threshold of 10 px, see Appendix A.2 on page 64. This figure contains the mean and confidence interval of the dwell time for each condition. Looking at the dwell time of the target, the velocity is the only independent variable, which has a significant effect. But these plots additionally show that this effect is minimal, since all mean values are more or less at the same height. This also shows, why neither the number of distractors nor the axis have a significant effect, since the only visible difference is between the mean values for a target velocity of 20 °/s. Regarding the dwell time of the distractors, the difference between the axis is visible. The average value for the vertical moving target is higher than the mean value for the horizontal axis for all conditions.

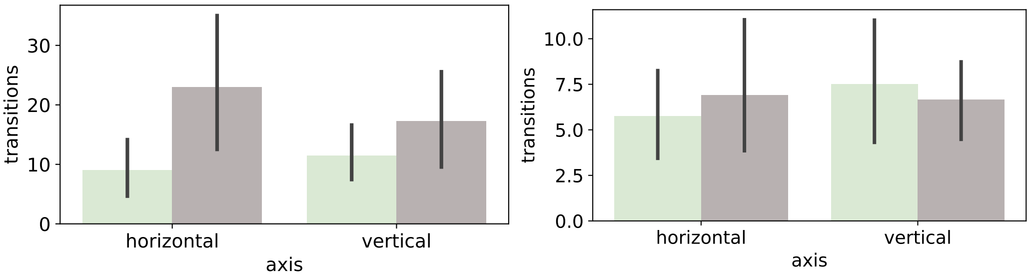
5.2.2 Transitions

A transition between AOIs occurs, when the participant shifts his gaze from the target to a distractor or vice versa. We implemented this by taking the AOI hit count described above (see Section 5.2 on page 37) and counting how often a distractor was hit immediately after the target was looked at. The results of this calculation are shown in Table 5.3 on the next page.

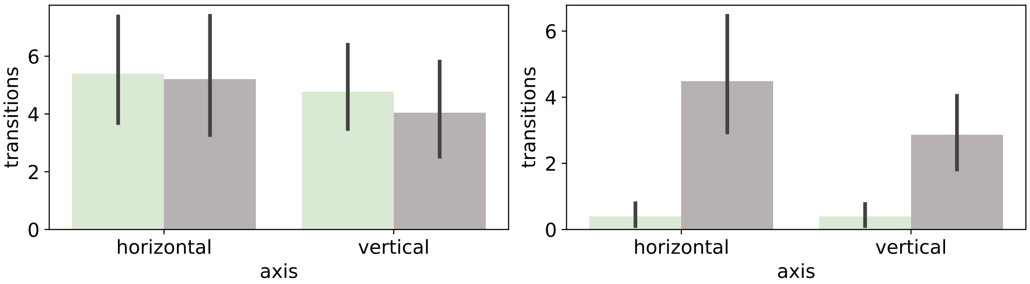
We used these values to perform two three-way ANOVAs for the same thresholds as above (10 and 20 px) on all independent variables and the number of transitions as the dependent variable. This resulted in a significant effect on the target velocity for both thresholds ($10\,\text{px}: F = 28.392,\ p < 0.001$ and $20\,\text{px}: F = 11.537,\ p < 0.01$). Additionally, we performed post hoc tests, using the same pairwise t test with Bonferroni correction as described in the previous section (see Section 5.2.1 on page 38). This resulted in several significant differences for the velocities 10 °/s and 5 °/s ($p = 0.0204$), 15 °/s and 5 °/s ($p < 0.01$) along with the last pair 20 °/s and 5 °/s ($p < 0.001$) for the first threshold of 10 px . Regarding the second threshold, there were significant differences, as well ($10\,°/\text{s}$ and $5\,°/\text{s}$: $p = 0.065$; $15\,°/\text{s}$ and $5\,°/\text{s}$: $p = 0.052$; $20\,°/\text{s}$ and $5\,°/\text{s}$: $p = 0.011$). For this section, we can reject the null hypothesis: “The target velocity has no influence on the transition between the target and any distractor, using a threshold of 10 px” and “The target velocity has no influence on the transition between the target and any distractor, using a threshold of 20 px”. For an illustration of the mean and confidence interval, see Figure 5.6. These plots illustrate clearly that there is a significant difference between the different target speeds and number of transitions.

target velocity	**number of distractors**	**axis**	**threshold 10 px**		**threshold 20 px**	
			M	SD	M	SD
5	1	horizontal	09.04	12.25	07.29	10.33
5	1	vertical	11.50	10.55	04.85	06.73
5	2	horizontal	22.96	29.28	13.88	19.10
5	2	vertical	17.25	20.00	11.23	16.61
10	1	horizontal	05.75	06.11	02.33	03.38
10	1	vertical	07.50	08.48	05.25	07.45
10	2	horizontal	06.90	09.17	03.02	05.66
10	2	vertical	06.65	05.36	05.88	06.78
15	1	horizontal	05.40	04.57	03.17	03.47
15	1	vertical	04.77	03.74	05.17	06.56
15	2	horizontal	05.21	05.23	03.56	03.98
15	2	vertical	04.04	04.14	03.73	02.82
20	1	horizontal	00.40	00.87	00.67	01.69
20	1	vertical	00.40	00.84	00.88	01.13
20	2	horizontal	04.48	04.26	04.71	07.04
20	2	vertical	02.85	02.83	03.48	02.56

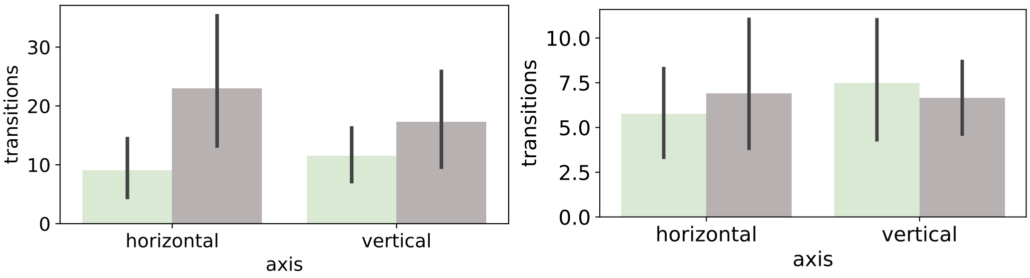
Table 5.3: Mean M and standard deviation SD of transitions between target and any distractor.



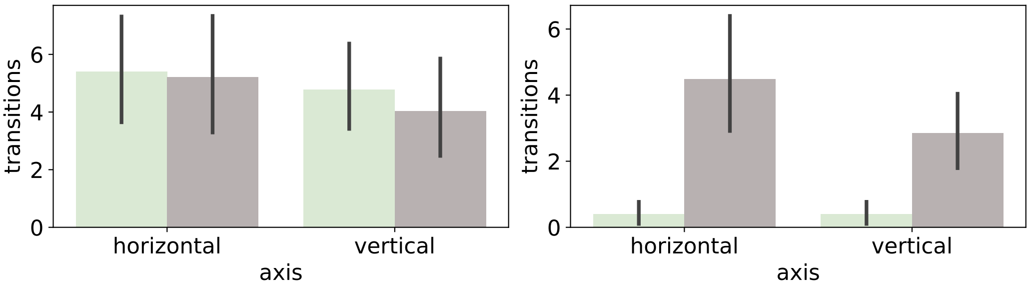
(a) target velocity: 5 °/s, threshold: 10 px **(b)** target velocity: 10 °/s, threshold: 10 px



(c) target velocity: 15 °/s, threshold: 10 px **(d)** target velocity: 20 °/s, threshold: 10 px



(e) target velocity: 5 °/s, threshold: 20 px **(f)** target velocity: 10 °/s, threshold: 20 px



(g) target velocity: 15 °/s, threshold: 20 px **(h)** target velocity: 20 °/s, threshold: 20 px

(i) Number of distractors

Figure 5.6: Bar plots containing the mean and confidence interval (95%) of the number of transitions for each threshold and condition.

5.3 Discussion

This section addresses the interpretation of the results. In general, the target velocity had the greatest impact of all three independent variables.

First, as stated above, the target velocity has an influence on the performance of SPEMs. Not only Section 5.1.1 on page 33, but also the offset between the target and gaze point showed that participants can follow slower targets better. The position (see Figure 5.2 on page 34) also showed similar results to plots in the review paper from Barnes [Bar08, p.310]. Here there was a latency when participants had to follow a target and they did stop a bit later than the target. The last effect is not visible in our plots, since the target stopped at the end of the video, the participant had no time to follow a target for longer than it was visible. Since the participants in our study knew, in which direction the shape would move, there was little latency when following the slower targets. For the faster ones, the latency was a bit higher, but when looking at the AOI hit plots in Figure 5.4 on page 37 and Appendix A.4 on page 79, most of the participants were able to follow the target right away, but shortly after the beginning they failed to keep up with the target speed. Comparing this effect to the state-of-the-art from Barnes [Bar08] (for the ramp stimulus), the participants from their study managed to follow the slower target sooner, as well. Furthermore, the statistical test on the dwell time (Section 5.2.1 on page 38) of the target showed the same effect of participants being able to follow faster targets not as good as slower ones. As the post hoc test determined, the greatest difference of the average values is between the fastest (20 °/s) and slowest (5 °/s) target velocity. Again, the target velocity has an influence on the number of transitions, as well. Here, the number of transitions decreased with a higher target speed. Since the participants had to make more effort to follow the target with a higher speed, this fact could be attributed to the lack of time to watch distractors. The post hoc test for the transitions between AOIs showed that the average of the slowest velocity (5 °/s) was significantly different, compared to all other velocities. These were not as different among each other.

Aside from the target velocity, the number of distractors seems to influence the percentage of time the participants looked at the distractors slightly. The results of the performed ANOVAs are not highly significant, for a threshold of 10 px regarding the AOI hit count, the number of distractors is only significant when using a confidence interval of 90 %. Additionally, both post hoc tests did not result in any significant differences, as well. This is interesting, since one condition contained two distractors the participants could look at, whereas the other condition only contained one. Considering that all conditions contained the same amount of intersections, this might be interpreted as the key factor. As shown in Figure 5.4 on page 37, most participants looked at the distractors shortly before the intersection, but not during the remaining time.

The last independent variable is the axis, which did not have a great influence, as well. There was a significant effect of the axis on the dwell time of all distractors when using a threshold of 20 px. The statistic tests showed that the participants tend to look longer at distractors when the target moved vertical. This might be because horizontal eye movements are mostly easier for people [RZD+96].

6 Conclusion and Future Work

This work addressed the effect of different factors on SPEMs. At first, we presented basic information about these kinds of eye movements, including the typical speed, trajectories and how appearance and spatial position of the target can impact them. We used this information to design our study, since we wanted to test how the presence of distractors influences SPEMs while the target moves at various velocities and in different directions. This chapter also covers the impact of cognitive factors on SPEMs. While the process of prediction is important, attention and mental effort in general do have an influence on these kinds of eye movements. Next, we searched for more related work by other people to determine the state-of-the-art and build our study accordingly. This helped us to decide, what factors we needed to include in our research. We then presented the system we used to create the video stimuli for our investigation. Afterwards, we presented the design of our study, including all independent variables and how we measured them. This contains the hardware, room setup and software, as well. Followed by a short section about the participants, this chapter was concluded with the procedure of the study. Lastly, we presented the results of our study. These contain three main parts, the first is the analysis of the velocity, the second one contains the spatial position of the target compared with the gaze data and the last one is about AOIs. The latter is divided into two sections about the dwell time and transitions between AOIs. We showed that the target velocity has the greatest influence on the performance of the participants. A slower target speed facilitates following it. This effect can be observed in the evaluation of the offset between the target and gaze point, as well. Another factor, which supports this, is the dwell time of the target, just as the transitions between the target and any distractor. The analysis of our study showed that the number of distractors has little influence on the dependent variables. The axis had even less significant effects than the number of distractors.

For the future, another possibility to evaluate this study could be to check if the speed changes in the presence of distractors. The velocity of the eye movement might slow down at the intersection because the participant is distracted, as one might expect. On the other hand, it is harder to maintain higher velocities, so there are probably differences between the different target speeds, as well. Aside from that, it would be possible to evaluate if the participants looked in the direction of the distractors for instance when they first started to move. Since we only checked, if the gaze position is within areas of interests, we did not include this factor. However, since this would indicate that the participant is distracted as well, this should be addressed in the future. Another interesting opportunity would be to analyse the kinds of eye movements, this would help to find catch-up saccades and would therefore contribute to understanding how well the participants were able to follow the target with the correct speed.

Regarding the design of the study, it would be possible to investigate, if any further trajectories have an influence on how people react when it comes to intersecting objects. As related work showed, there are easier and harder trajectories for humans to perform, so this might result in even more cognitive workload. There are several ways, in which people might react. One being the possibility that people tend to look at the distraction more often because this requires less effort than to follow the target, or they could not notice it at all for the simple reason that the main task demands all their attention.

Furthermore, there are many possibilities, how the experiment can be modified. Not only the appearance and position of both the target and the distractors, but as mentioned above the trajectory and speed can be changed. In addition, the mental effort can be increased by additional tasks or moving backgrounds.

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[Weg12] J. Wegener, ed. *WPF 4.5 und XAML: Grafische Benutzeroberflächen für Windows inkl. Entwicklung von Windows Store Apps*. Deutsch. Hanser eLibrary. München: Hanser Verlag, 2012. ISBN: 978-3-446-43467-7 (Druck-Ausgabe). URL: `http://dx.doi.org/10.3139/9783446435414` (cit. on p. 19).

[WES54] G. WESTHEIMER. “EYE MOVEMENT RESPONSES TO A HORIZONTALLY MOVING VISUAL STIMULUS”. In: *A.M.A. Archives of Ophthalmology* 52.6 (Dec. 1954), pp. 932–941. ISSN: 0096-6339. DOI: `10.1001/archopht.1954.00920050938013`. eprint: `https://jamanetwork.com/journals/jamaophthalmology/articlepdf/624384/archopht\_52\_6\_013.pdf`. URL: `https://dx.doi.org/10.1001/archopht.1954.00920050938013` (cit. on p. 15).

All links were last followed on March 31, 2019.

A Appendix

This chapter contains additional plots. It is separated in four sections, containing the velocity, bar plots, position and AOI plots.

A.1 Velocity plots

Here, the mean gaze velocity is shown in comparison with the target velocity. There is one plot for every condition, the target velocity is shown as a black line.

Axis: vertical

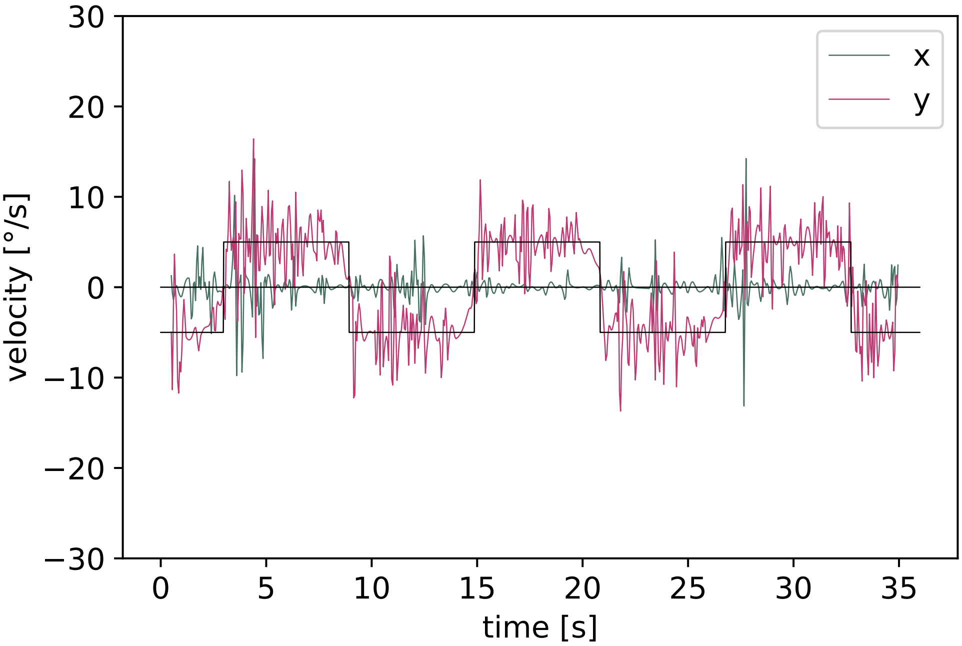


Figure A.1: velocity: 5 °/s, number of distractors: 0, axis: vertical

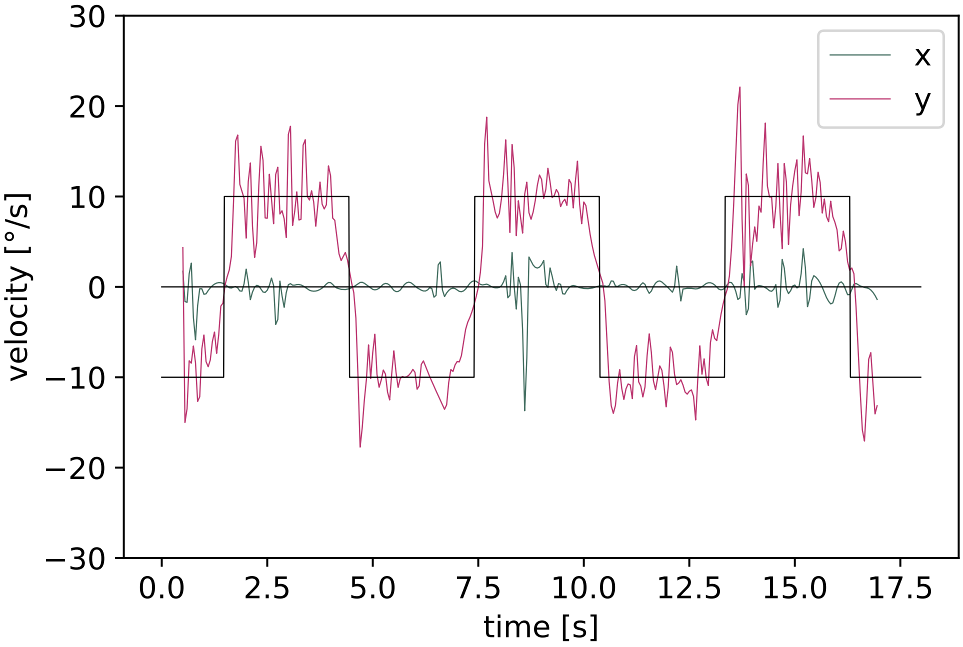


Figure A.2: velocity: 10 °/s, number of distractors: 0, axis: vertical

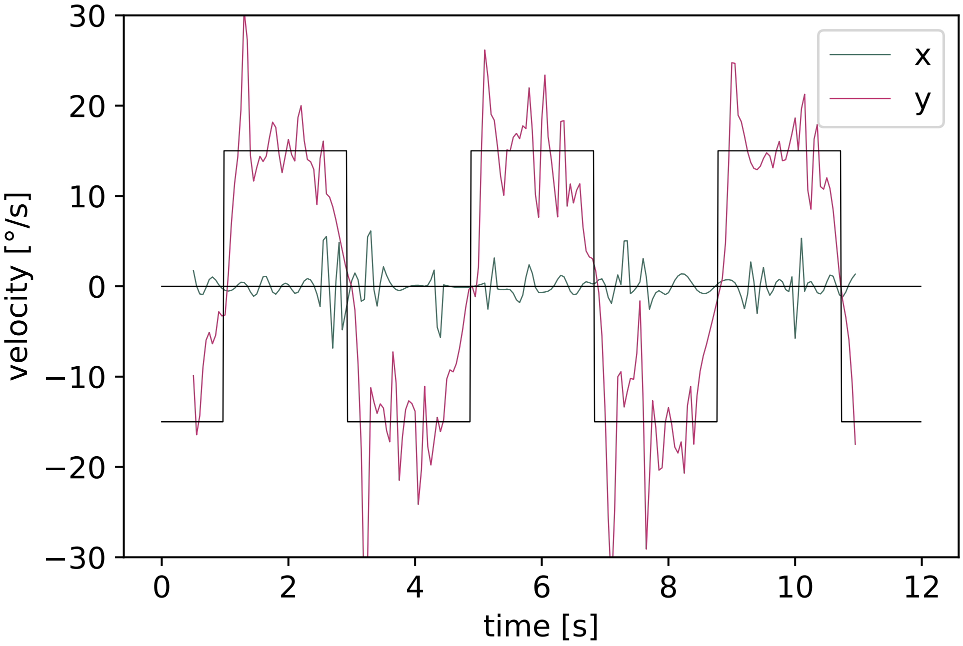


Figure A.3: velocity: 15 °/s, number of distractors: 0, axis: vertical

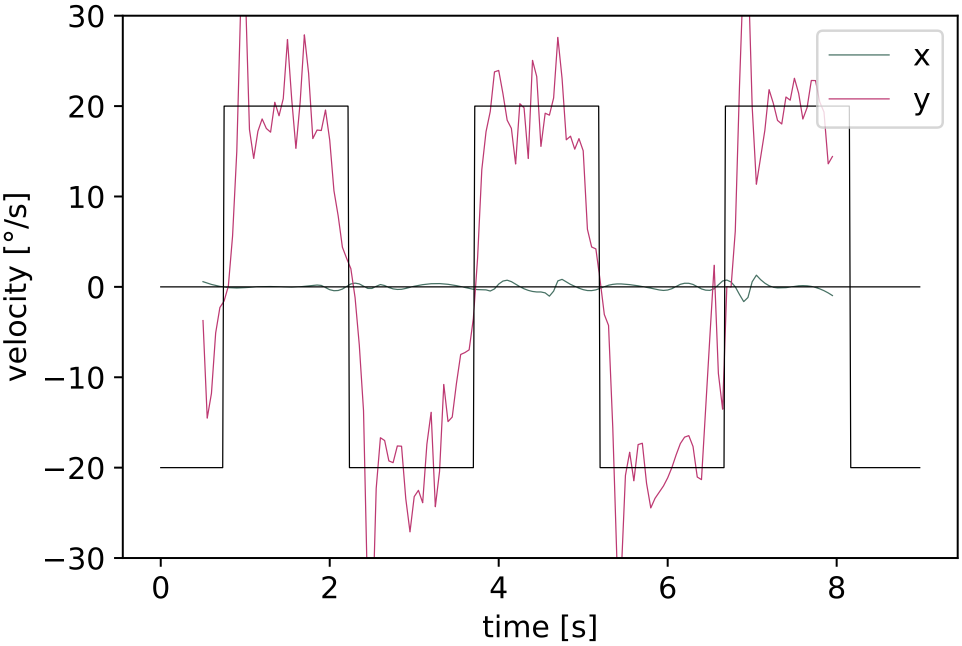


Figure A.4: velocity: 20 °/s, number of distractors: 0, axis: vertical

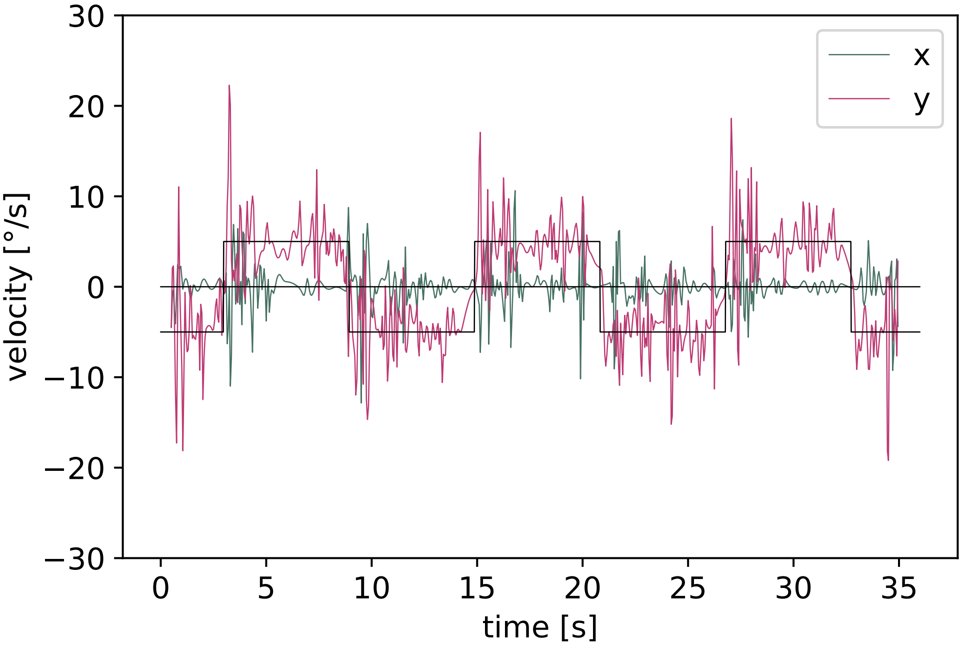


Figure A.5: velocity: 5 °/s, number of distractors: 1, axis: vertical

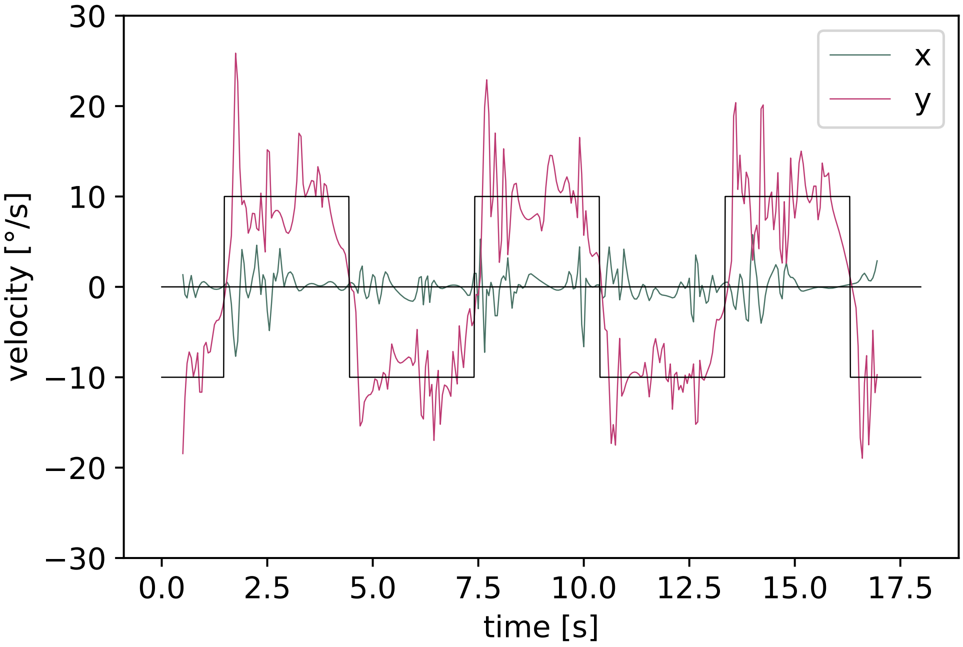


Figure A.6: velocity: 10 °/s, number of distractors: 1, axis: vertical

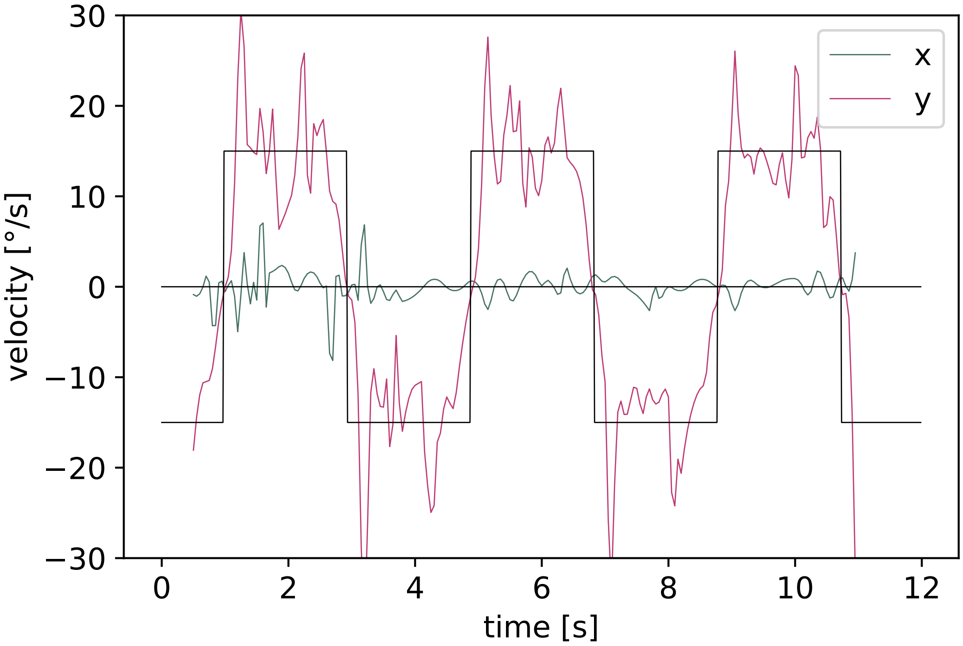


Figure A.7: velocity: 15 °/s, number of distractors: 1, axis: vertical

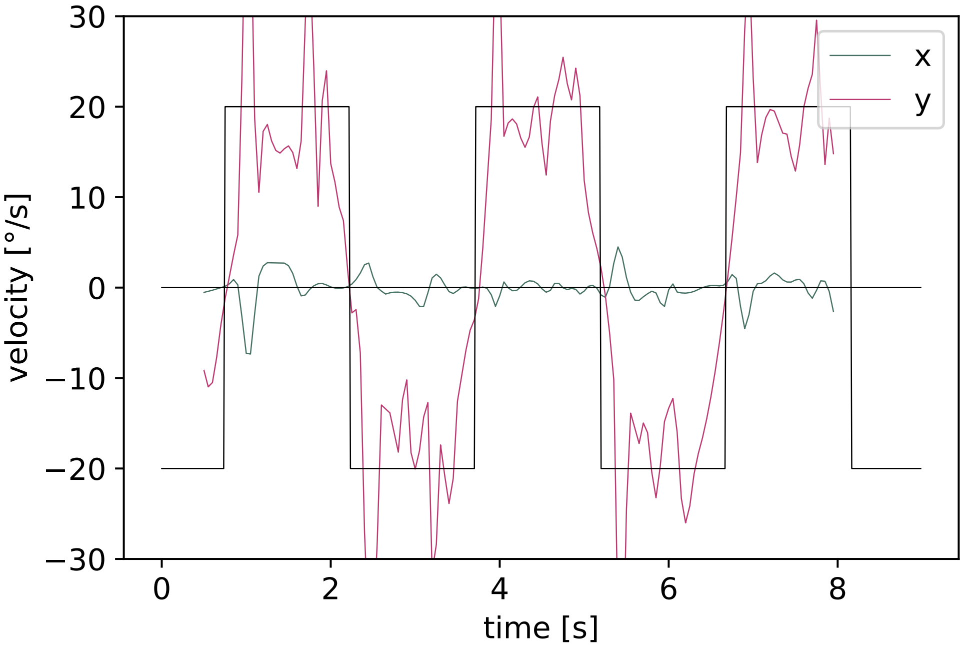


Figure A.8: velocity: 20 °/s, number of distractors: 1, axis: vertical

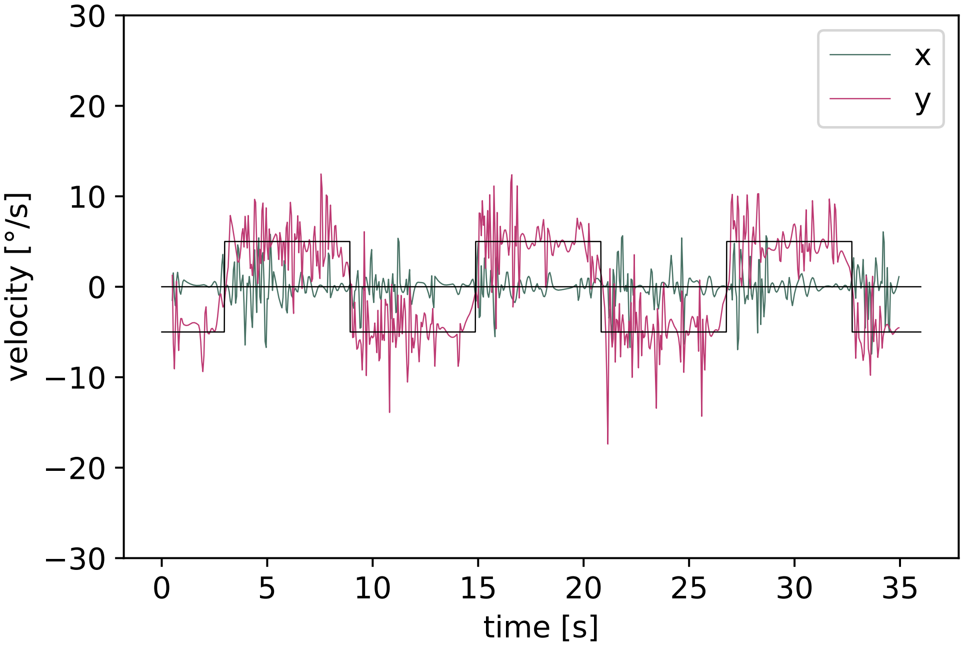


Figure A.9: velocity: 5 °/s, number of distractors: 2, axis: vertical

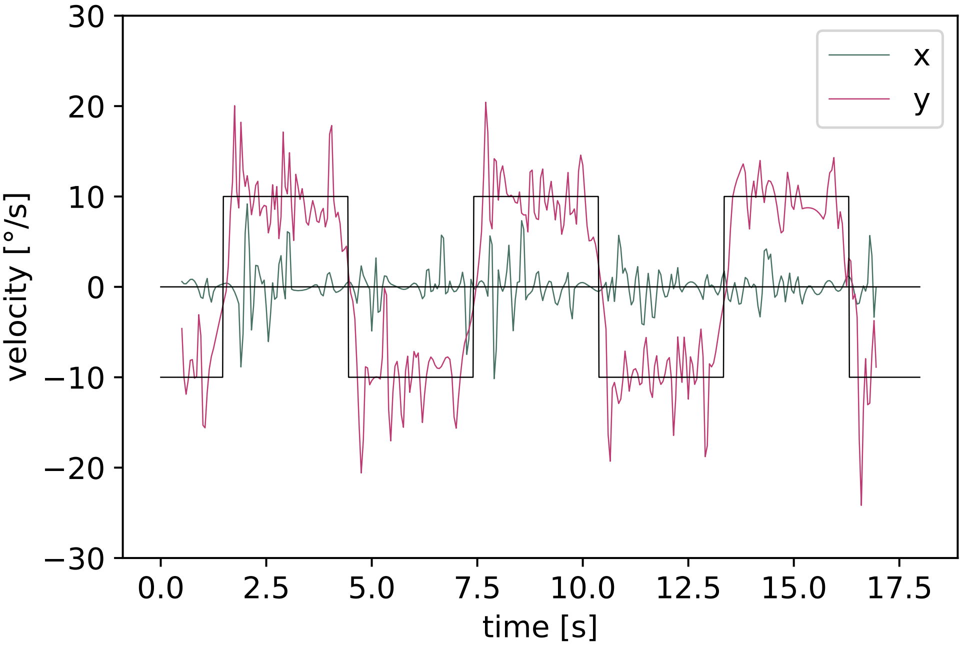


Figure A.10: velocity: 10 °/s, number of distractors: 2, axis: vertical

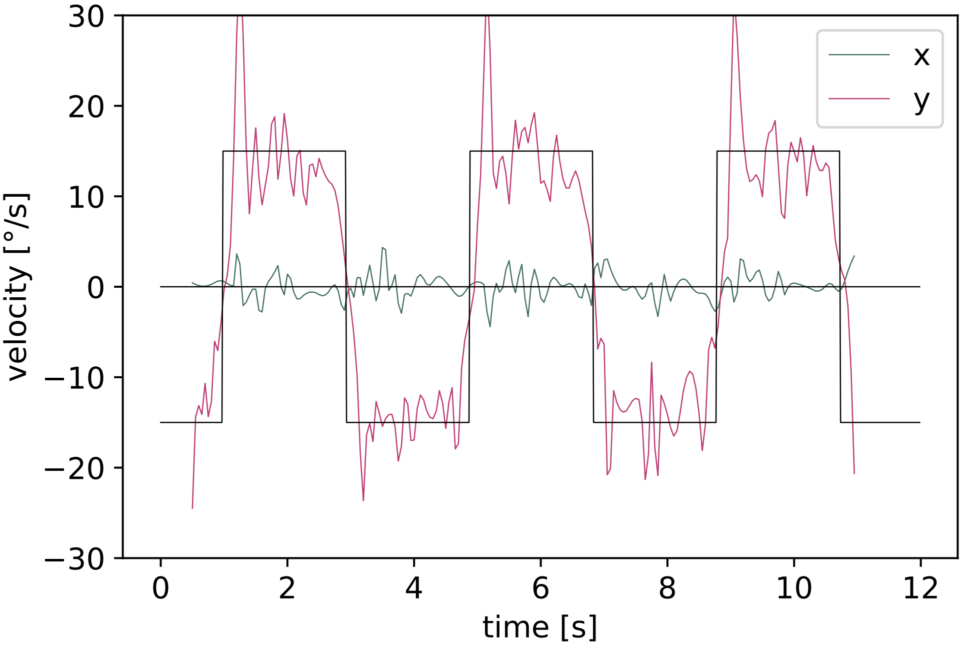


Figure A.11: velocity: 15 °/s, number of distractors: 2, axis: vertical

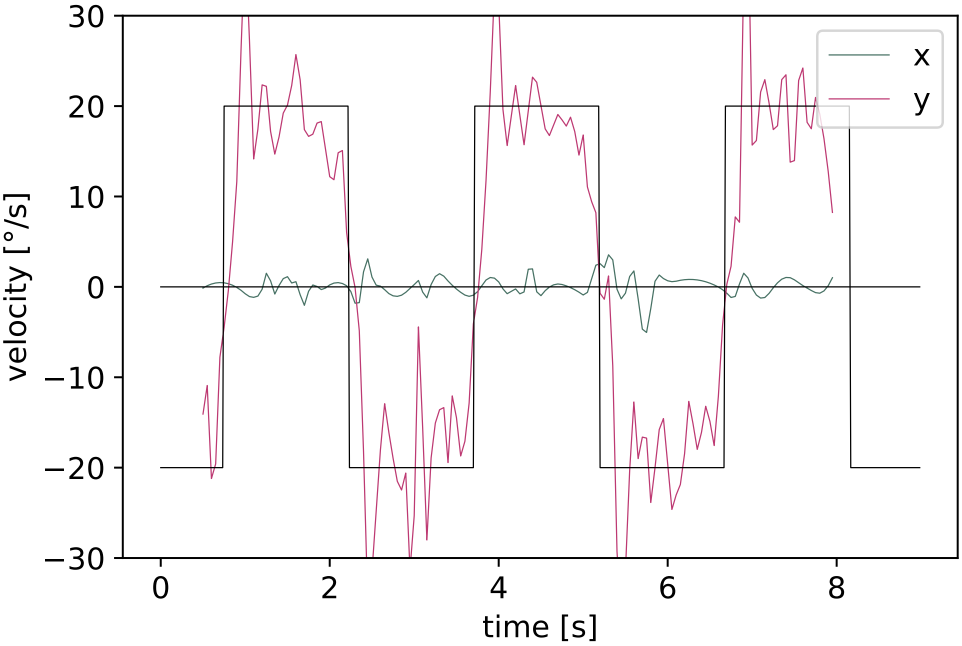


Figure A.12: velocity: 20 °/s, number of distractors: 2, axis: vertical

Axis: horizontal

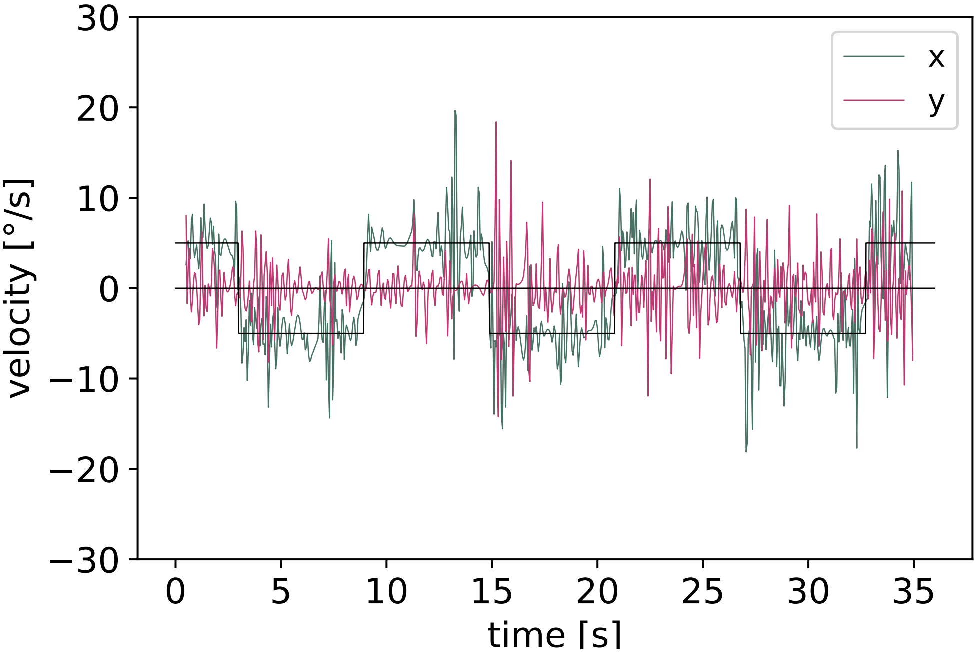


Figure A.13: velocity: 5 °/s, number of distractors: 0, axis: horizontal

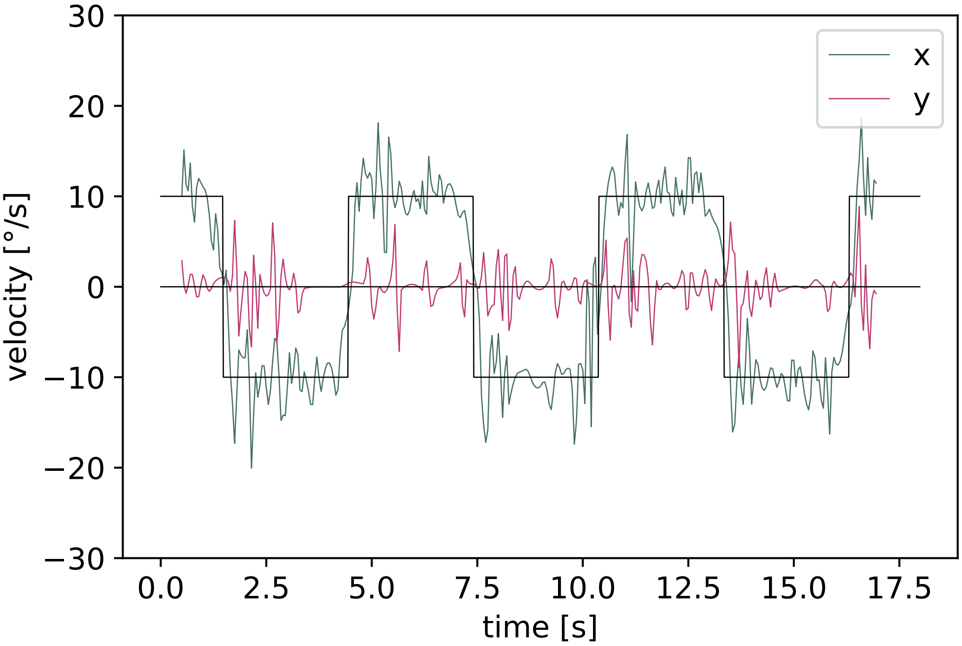


Figure A.14: velocity: 10 °/s, number of distractors: 0, axis: horizontal

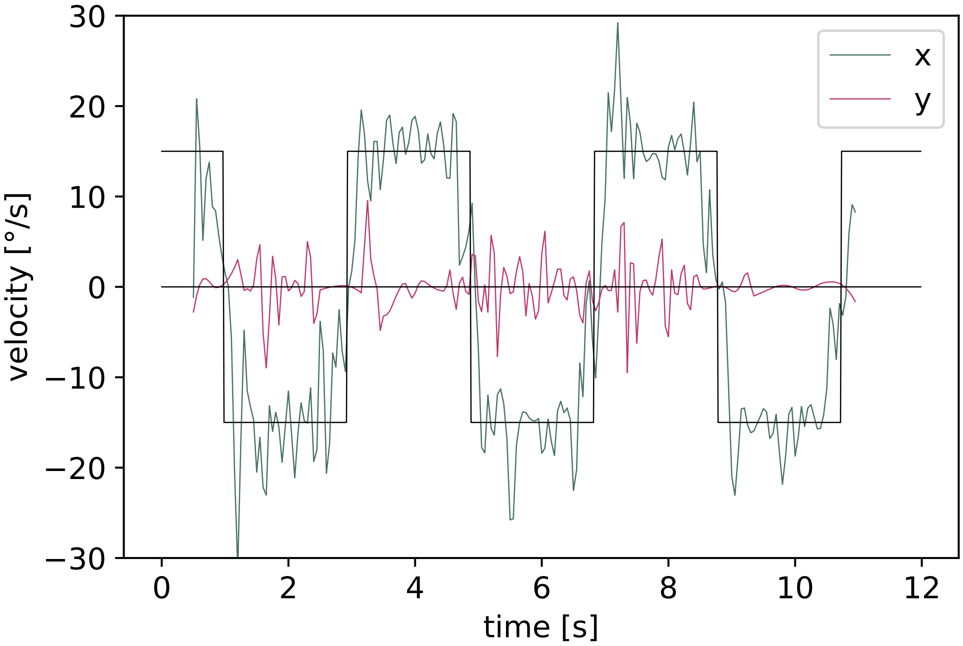


Figure A.15: velocity: 15 °/s, number of distractors: 0, axis: horizontal

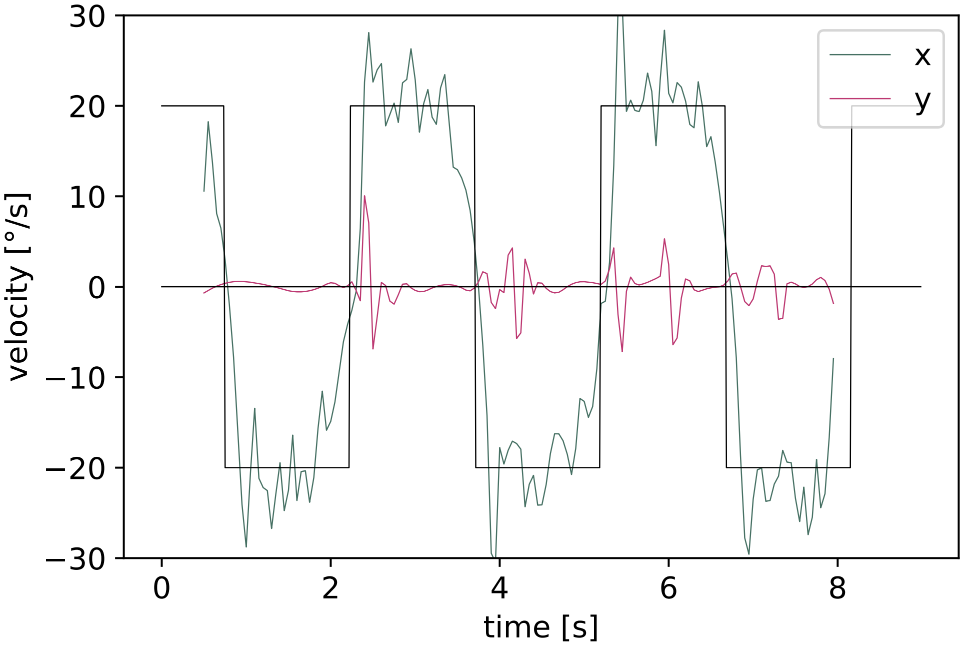


Figure A.16: velocity: 20 °/s, number of distractors: 0, axis: horizontal

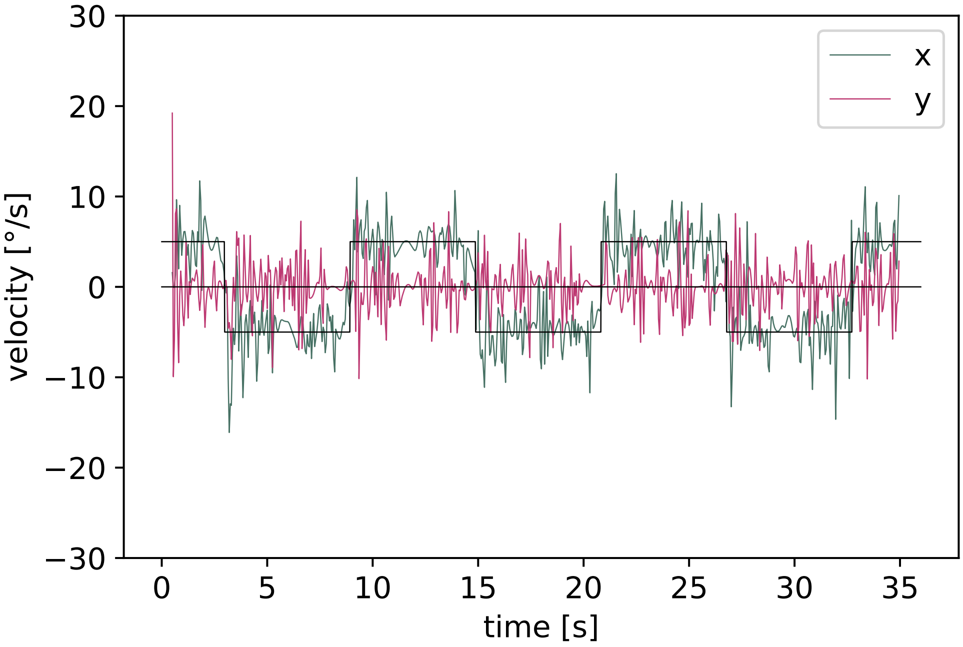


Figure A.17: velocity: 5 °/s, number of distractors: 1, axis: horizontal

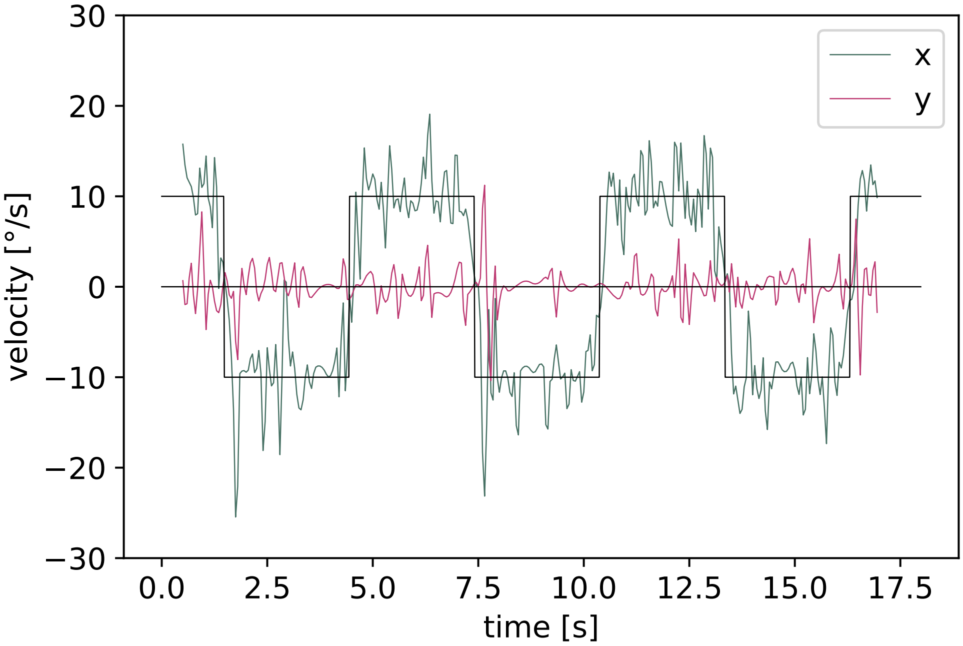


Figure A.18: velocity: 10 °/s, number of distractors: 1, axis: horizontal

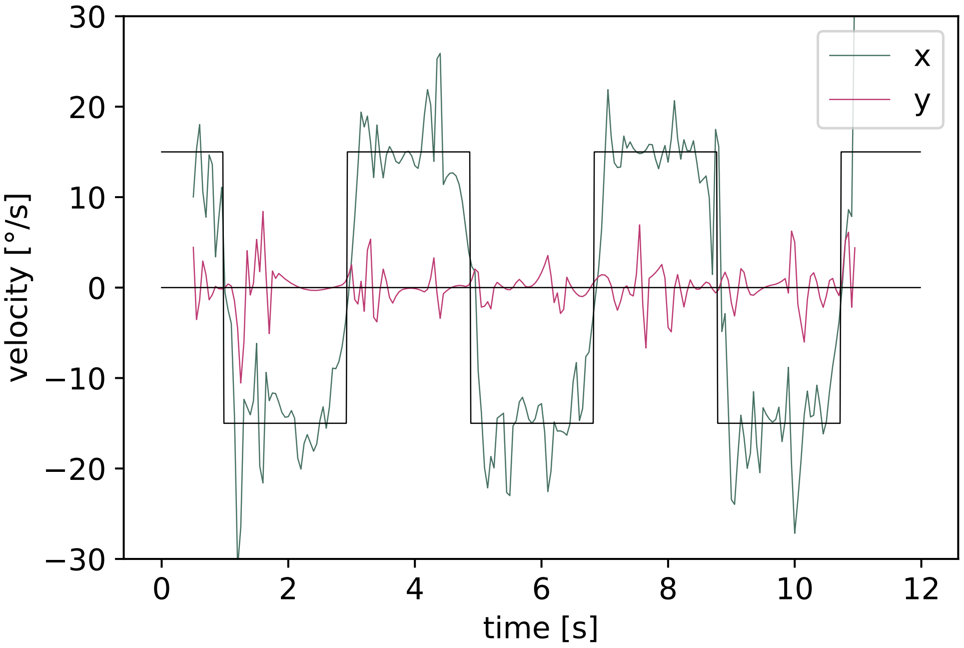


Figure A.19: velocity: 15 °/s, number of distractors: 1, axis: horizontal

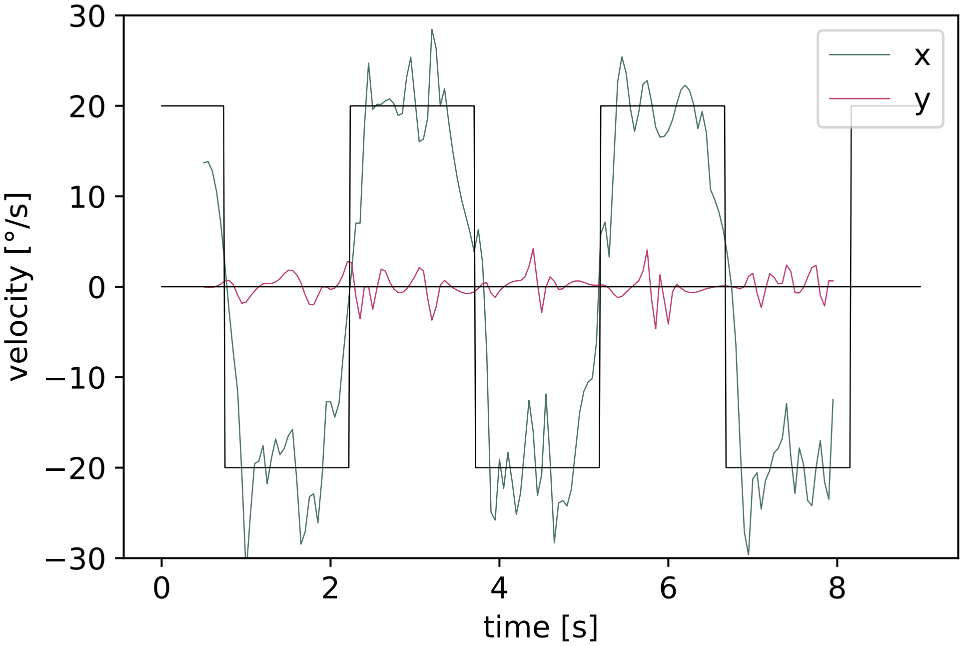


Figure A.20: velocity: 20 °/s, number of distractors: 1, axis: horizontal

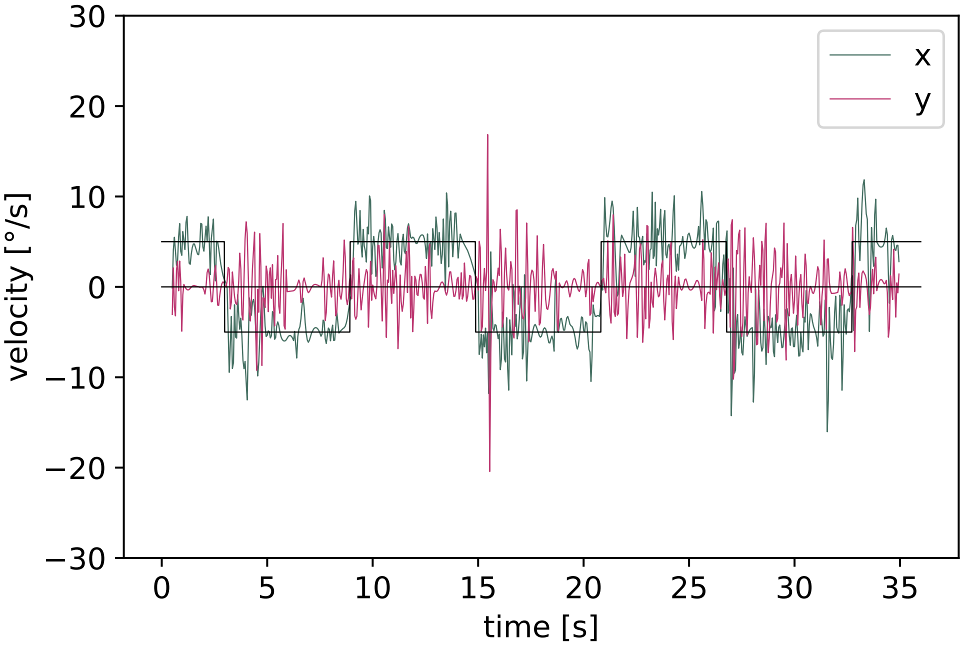


Figure A.21: velocity: 5 °/s, number of distractors: 2, axis: horizontal

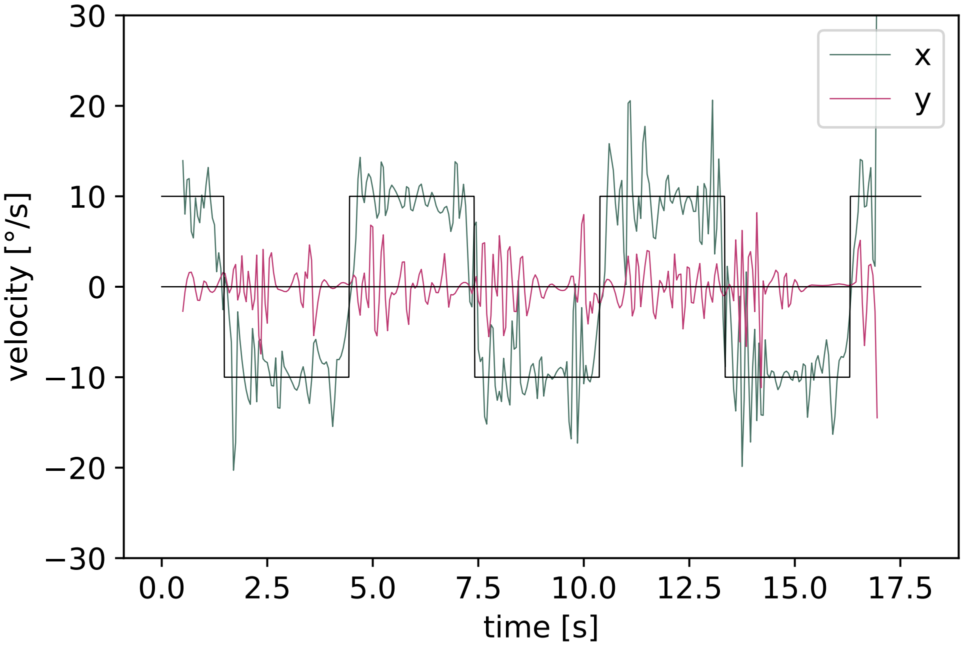


Figure A.22: velocity: 10 °/s, number of distractors: 2, axis: horizontal

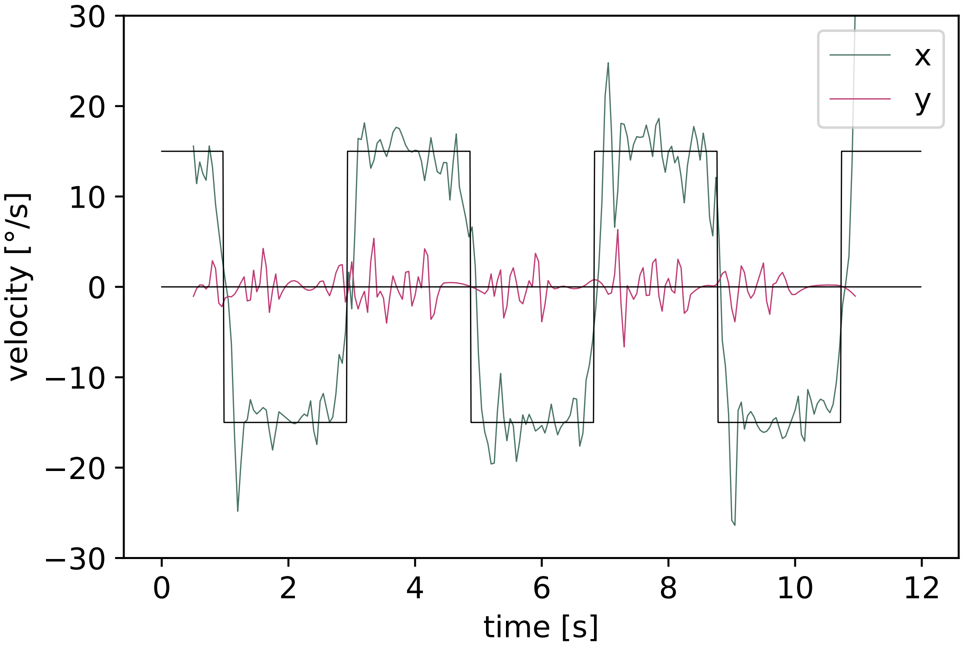


Figure A.23: velocity: 15 °/s, number of distractors: 2, axis: horizontal

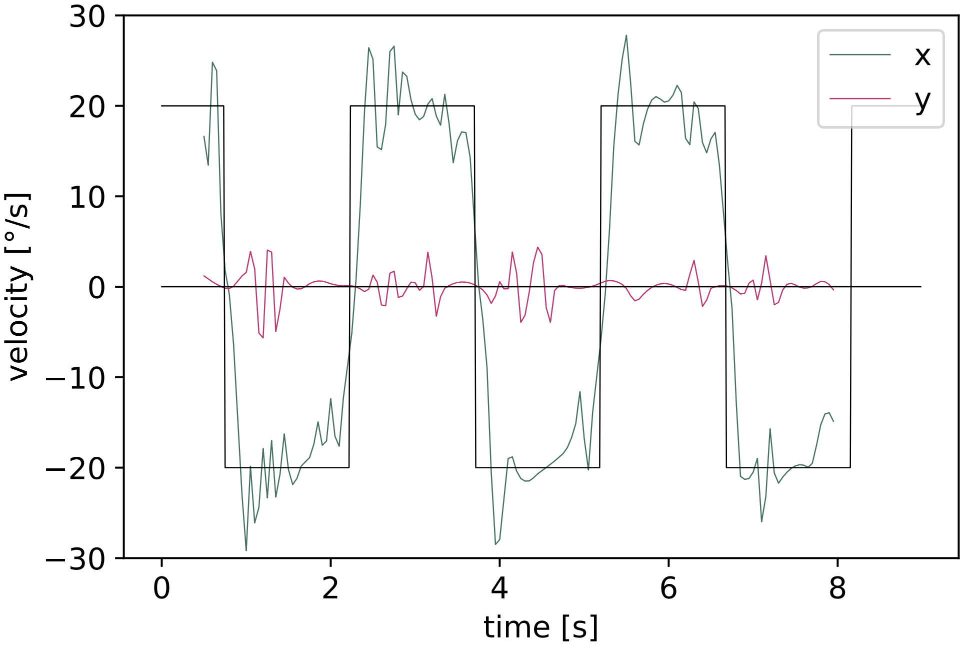
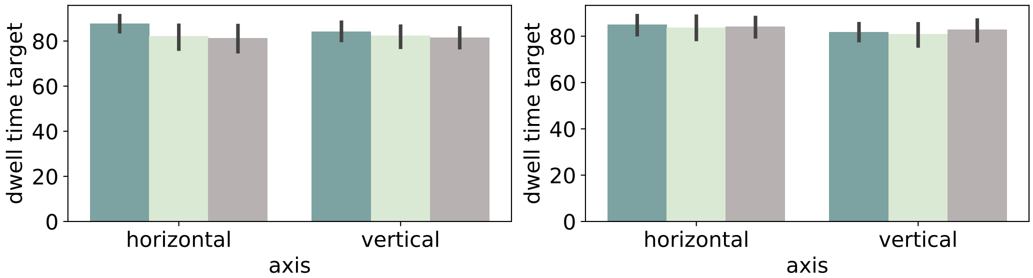
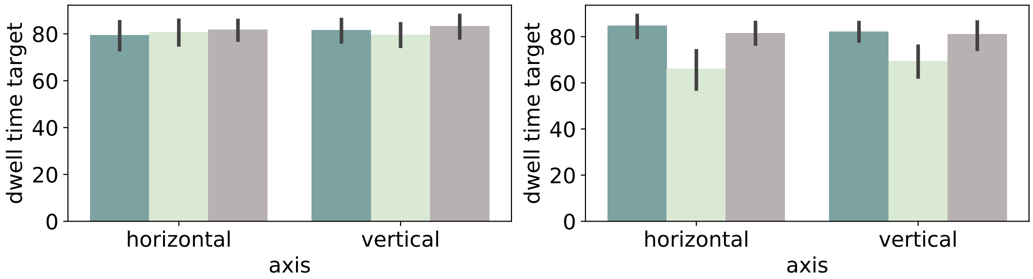


Figure A.24: velocity: 20 °/s, number of distractors: 2, axis: horizontal

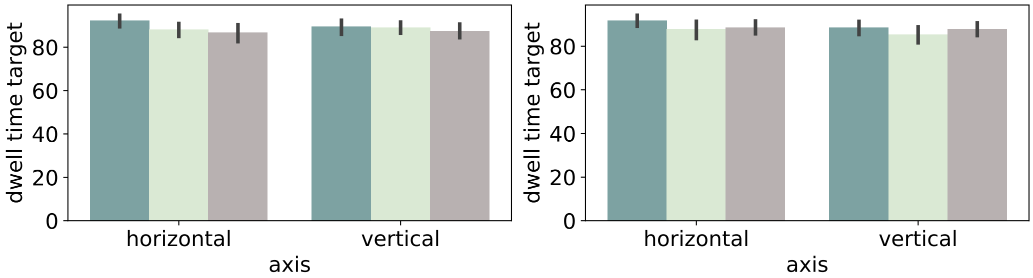
A.2 Bar plots



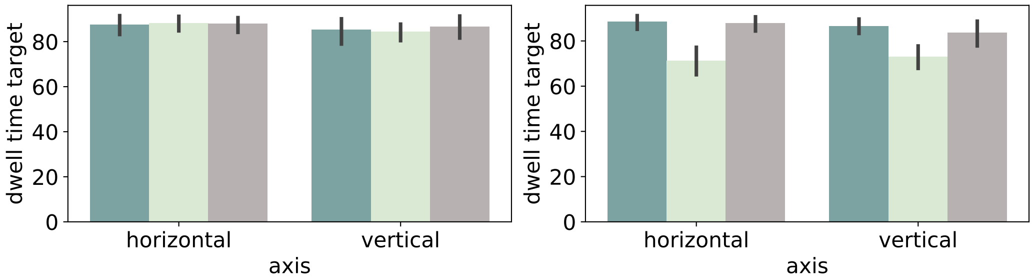
(a) target velocity: 5 °/s, threshold: 10 px **(b)** target velocity: 10 °/s, threshold: 10 px



(c) target velocity: 15 °/s, threshold: 10 px **(d)** target velocity: 20 °/s, threshold: 10 px



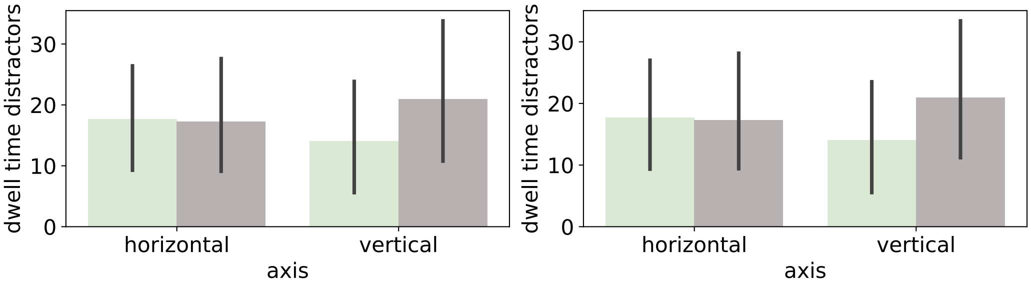
(e) target velocity: 5 °/s, threshold: 20 px **(f)** target velocity: 10 °/s, threshold: 20 px



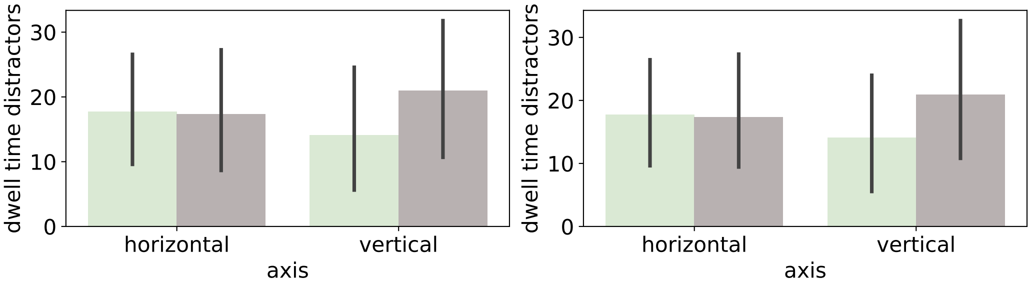
(g) target velocity: 15 °/s, threshold: 20 px **(h)** target velocity: 20 °/s, threshold: 20 px

(i) Number of distractors

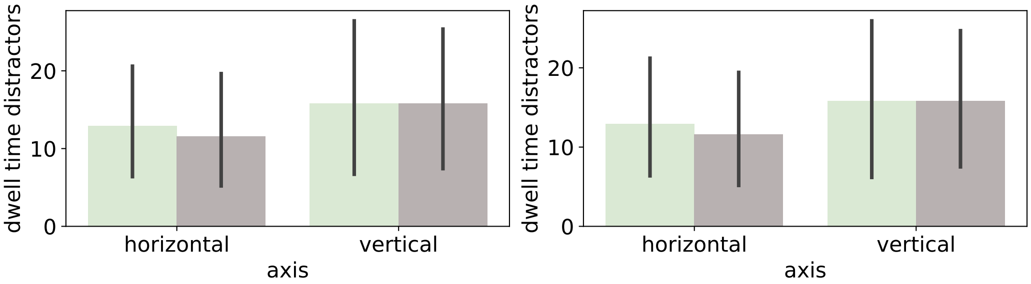
Figure A.25: Bar plots containing the mean and confidence interval (95%) of the dwell time of the target for all thresholds and conditions.



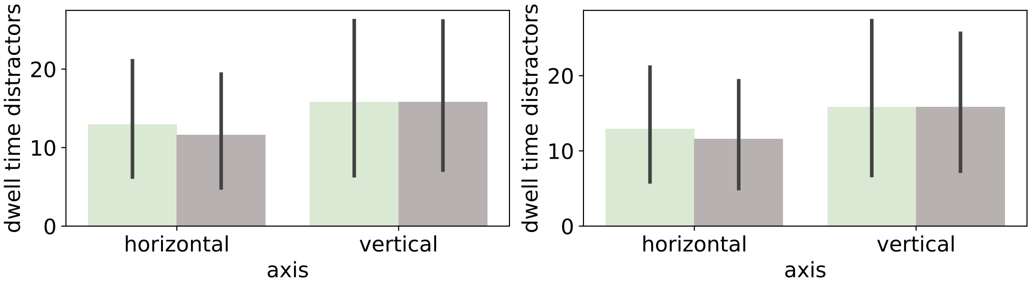
(a) target velocity: 5 °/s, threshold: 10 px **(b)** target velocity: 10 °/s, threshold: 10 px



(c) target velocity: 15 °/s, threshold: 10 px **(d)** target velocity: 20 °/s, threshold: 10 px



(e) target velocity: 5 °/s, threshold: 20 px **(f)** target velocity: 10 °/s, threshold: 20 px



(g) target velocity: 15 °/s, threshold: 20 px **(h)** target velocity: 20 °/s, threshold: 20 px

(i) Number of distractors

Figure A.26: Bar plots containing the mean and confidence interval (95%) of the dwell time of the distractors for all thresholds and conditions.

A.3 Position plots

This section shows the position plots for each condition. The spatial position of the target is represented by a grey line, whereas the x and y coordinates of the mean gaze data are plotted as a red and green line. The grey dots are the intersection between the target and any distractor. The headings divide the following plots into two sections to facilitate finding the right plot.

Axis: vertical

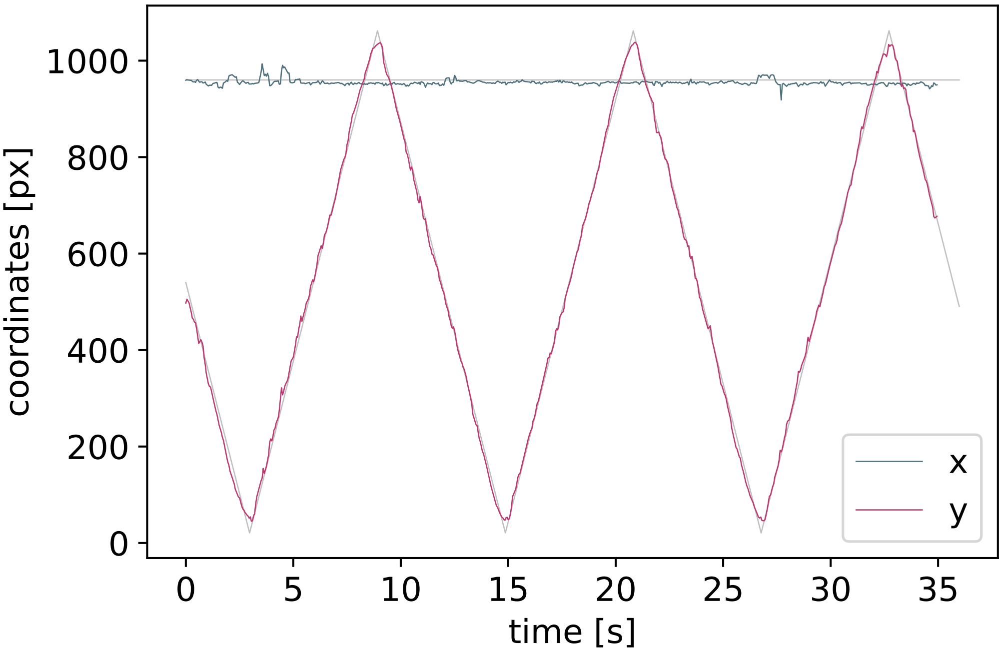


Figure A.27: velocity: 5 °/s, number of distractors: 0, axis: vertical

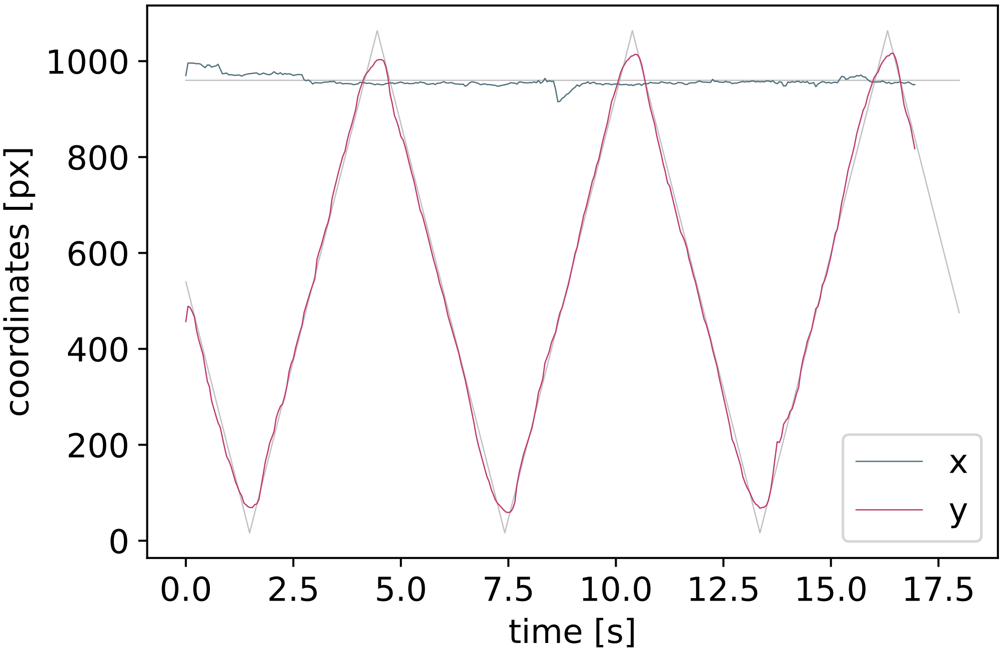


Figure A.28: velocity: 10 °/s, number of distractors: 0, axis: vertical

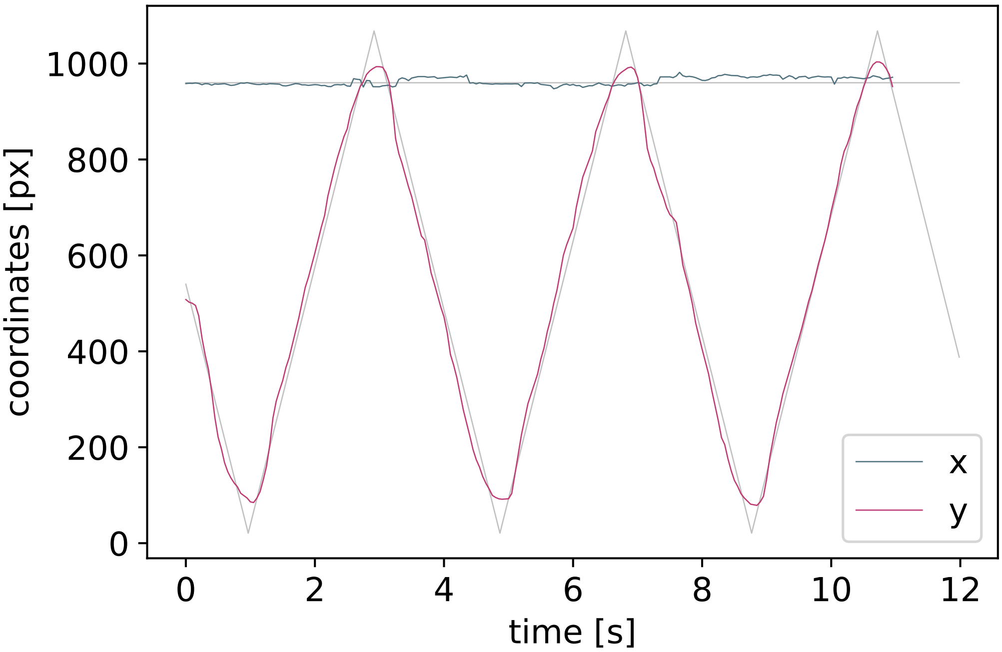


Figure A.29: velocity: 15 °/s, number of distractors: 0, axis: vertical

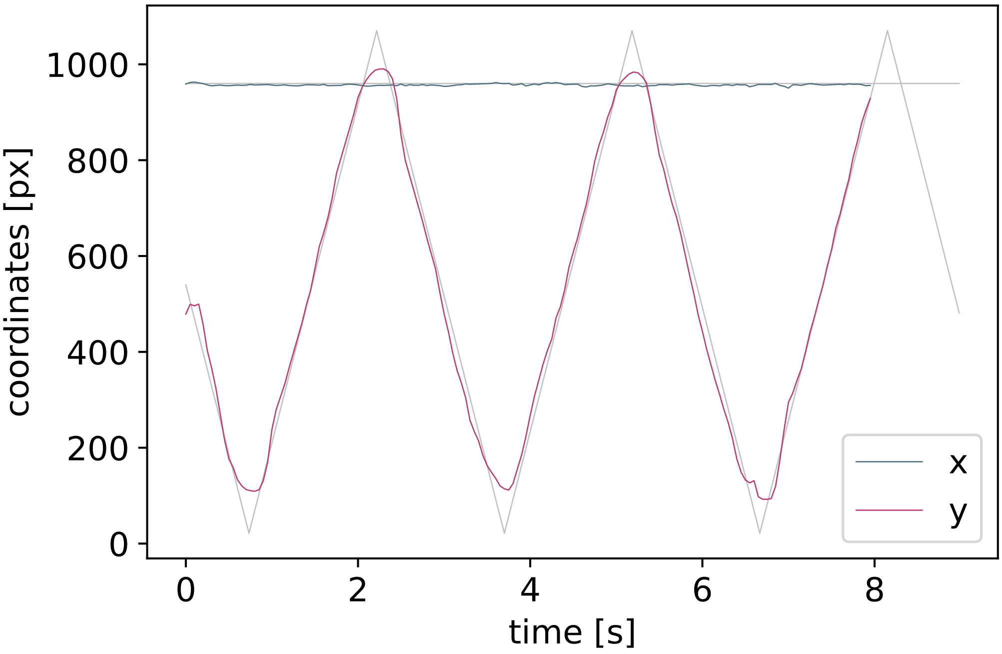


Figure A.30: velocity: 20 °/s, number of distractors: 0, axis: vertical

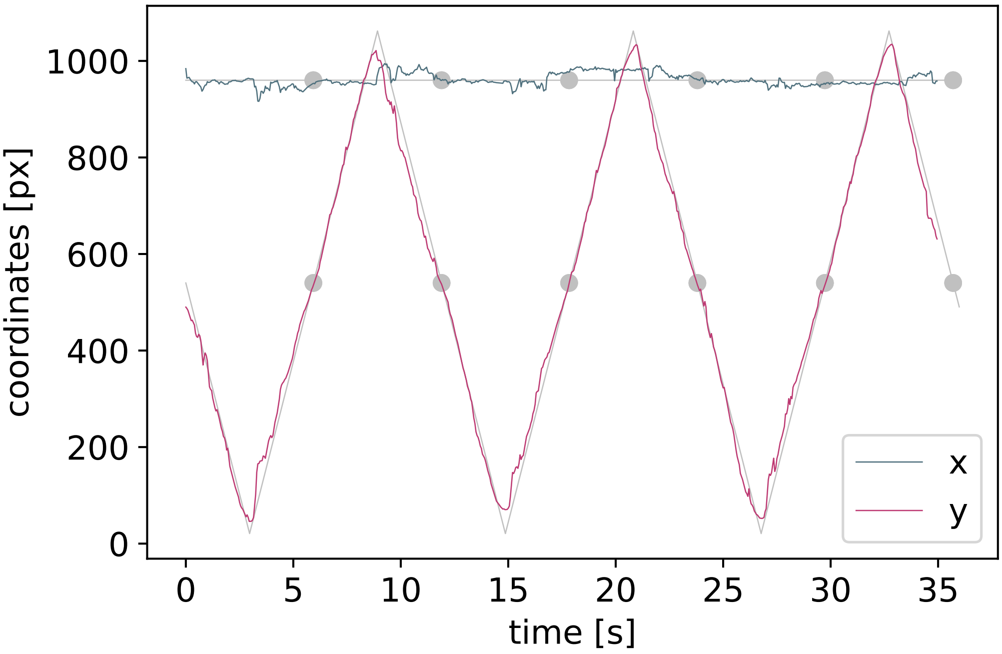


Figure A.31: velocity: 5 °/s, number of distractors: 1, axis: vertical

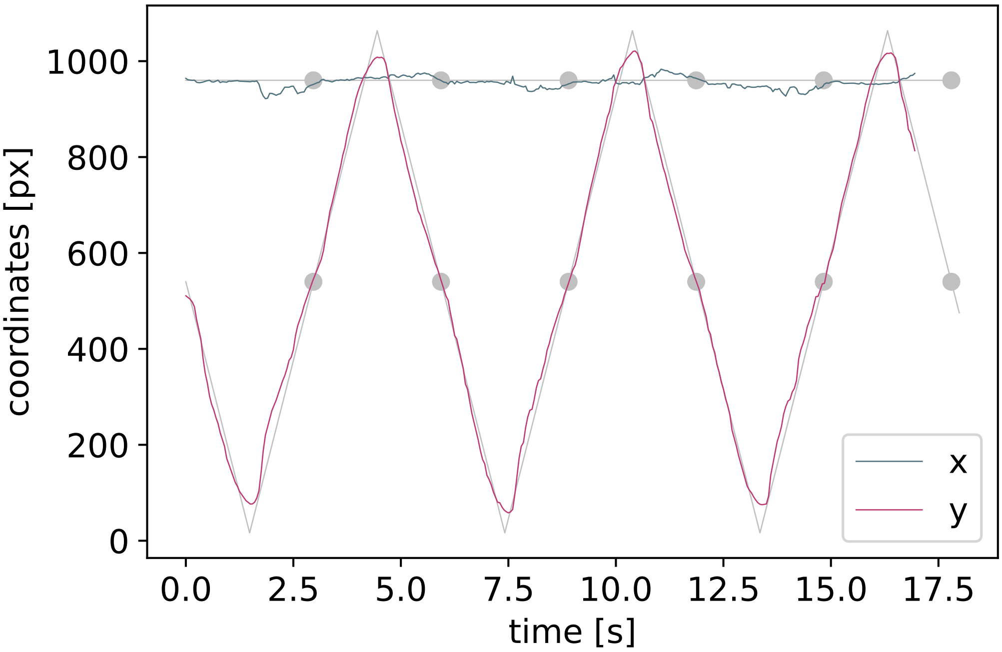


Figure A.32: velocity: 10 °/s, number of distractors: 1, axis: vertical

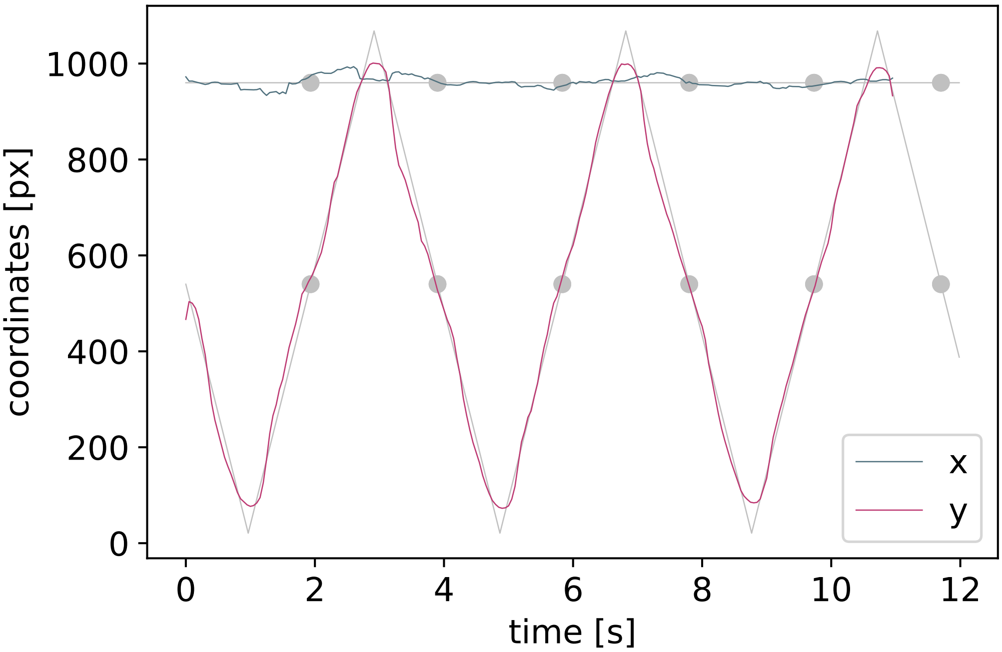


Figure A.33: velocity: 15 °/s, number of distractors: 1, axis: vertical

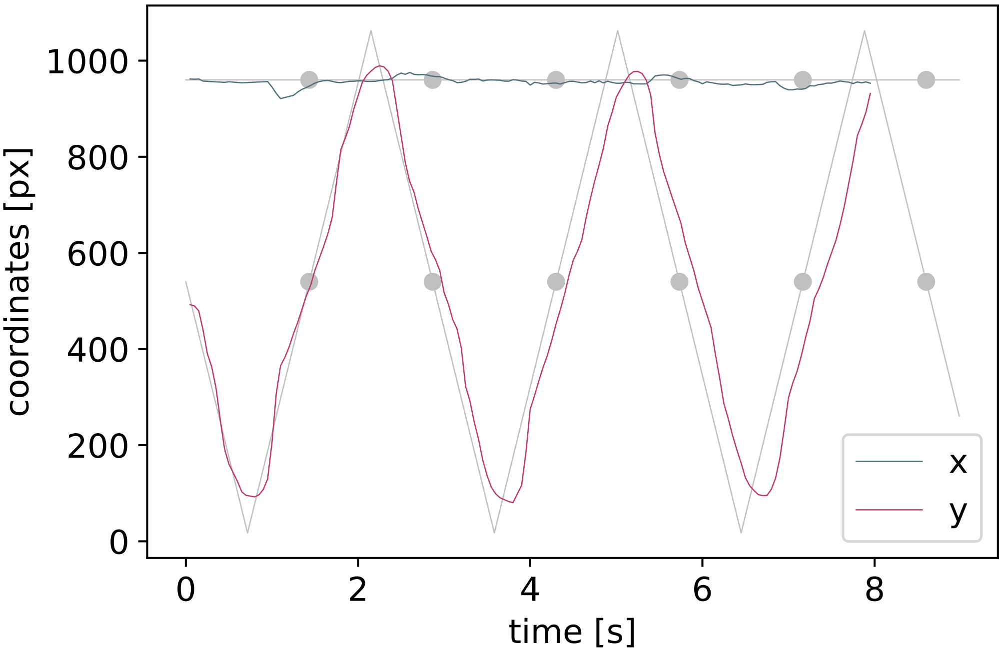


Figure A.34: velocity: 20 °/s, number of distractors: 1, axis: vertical

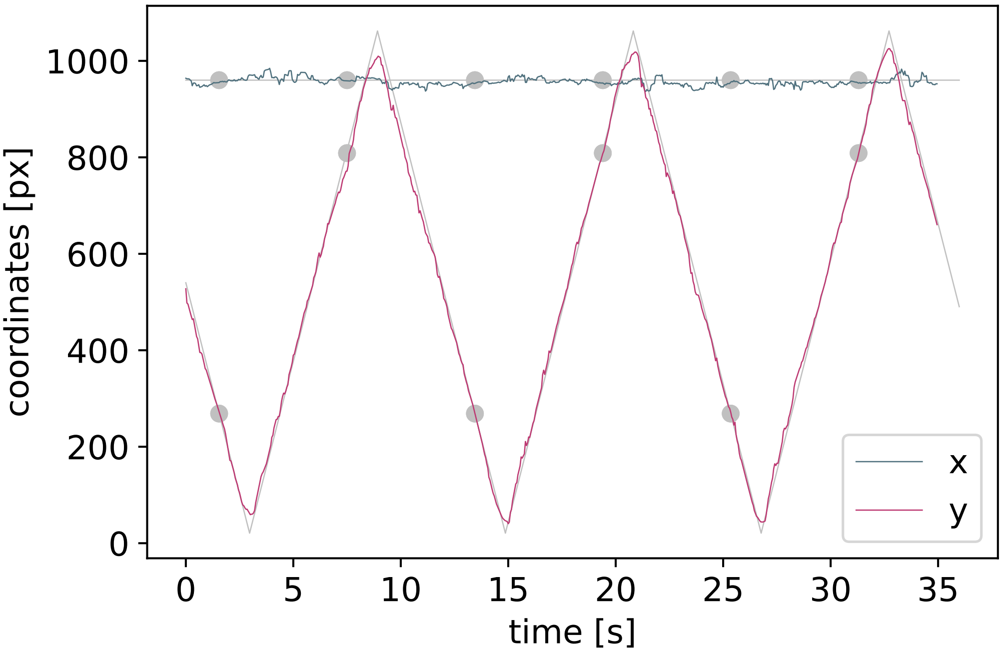


Figure A.35: velocity: 5 °/s, number of distractors: 2, axis: vertical

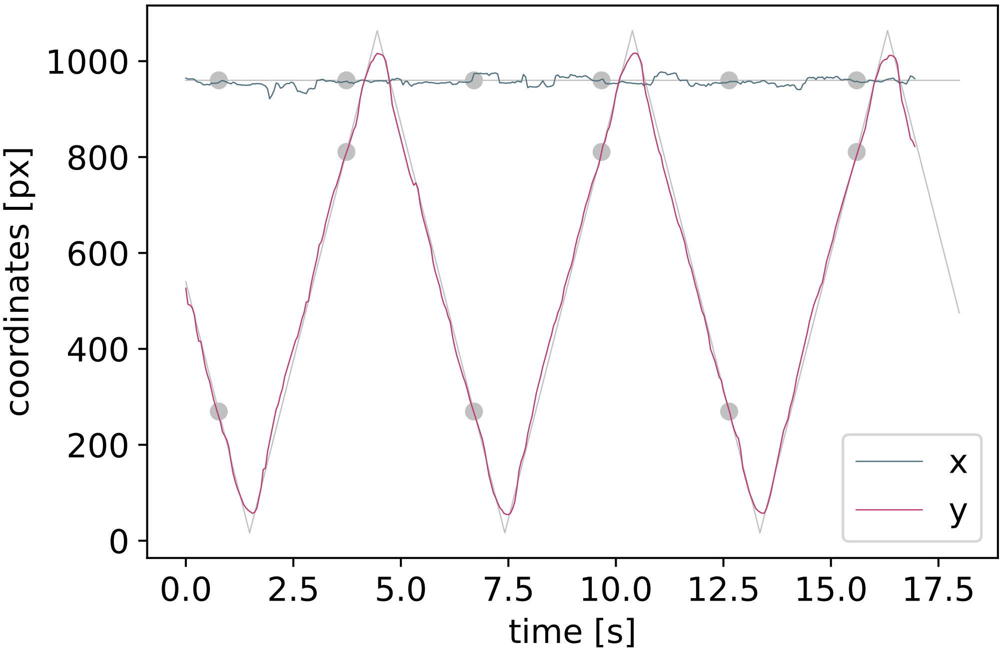


Figure A.36: velocity: 10 °/s, number of distractors: 2, axis: vertical

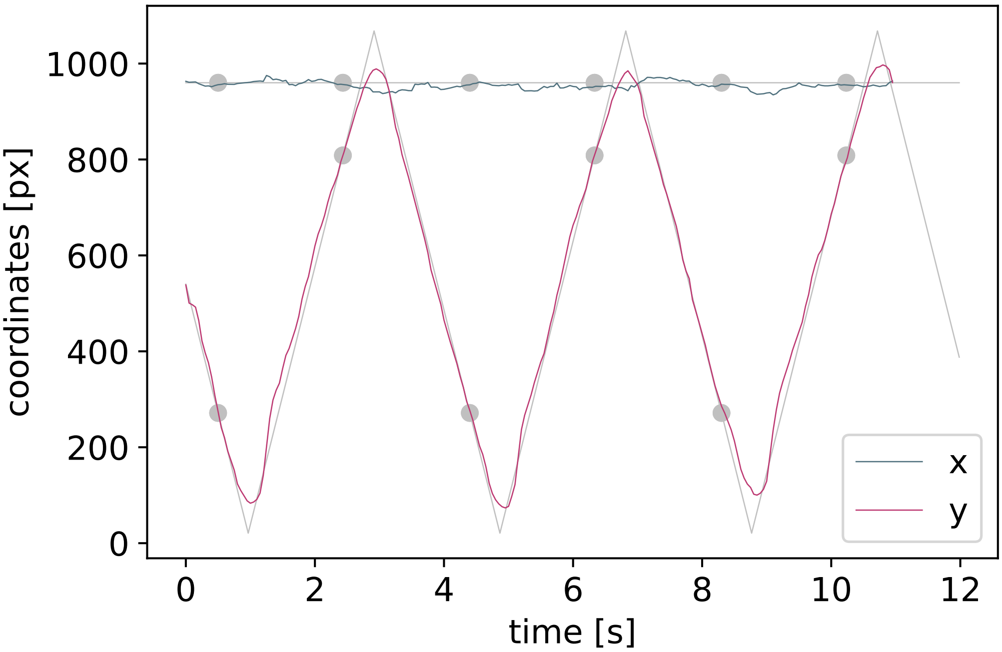


Figure A.37: velocity: 15 °/s, number of distractors: 2, axis: vertical

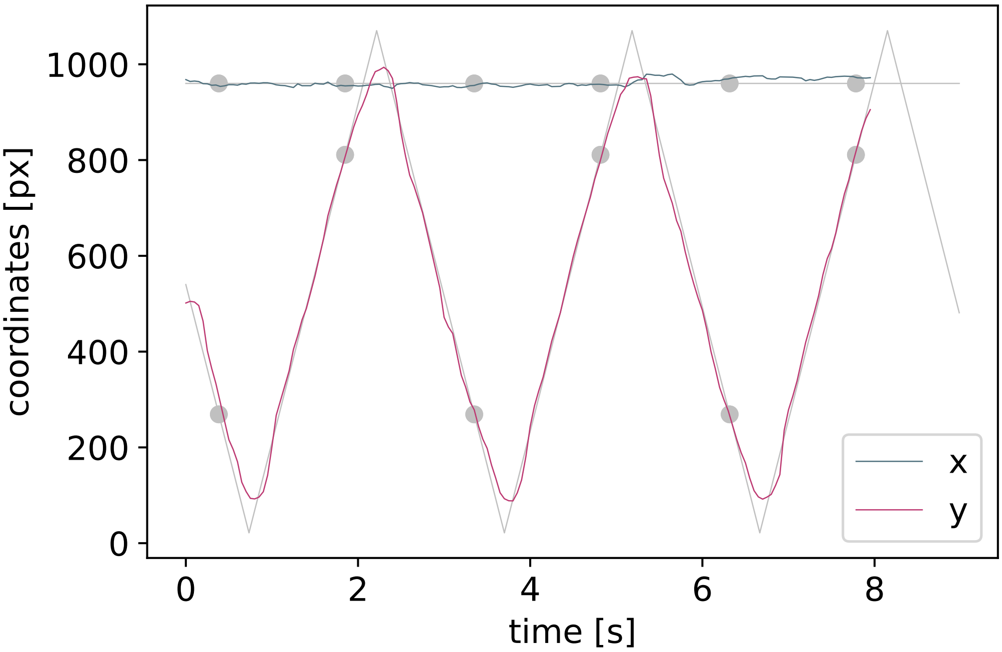


Figure A.38: velocity: 20 °/s, number of distractors: 2, axis: vertical

Axis: horizontal

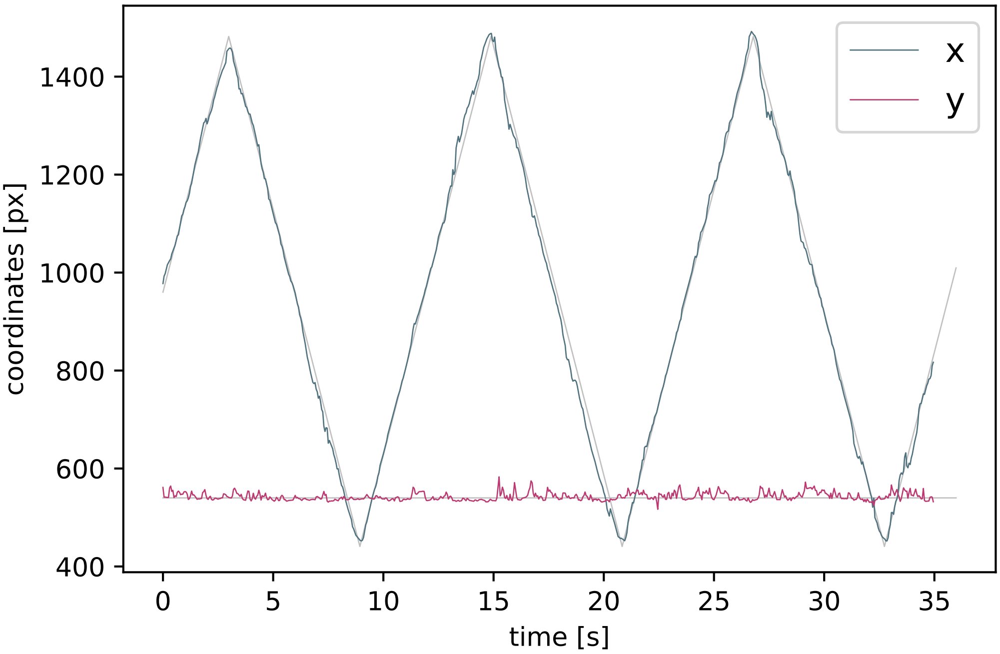


Figure A.39: velocity: 5 °/s, number of distractors: 0, axis: horizontal

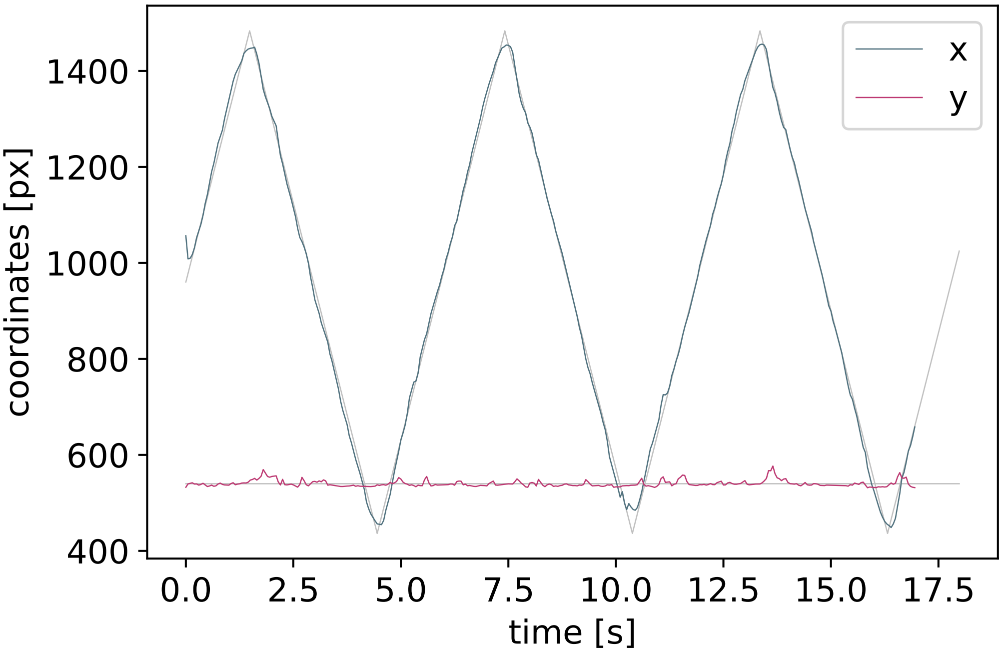


Figure A.40: velocity: 10 °/s, number of distractors: 0, axis: horizontal

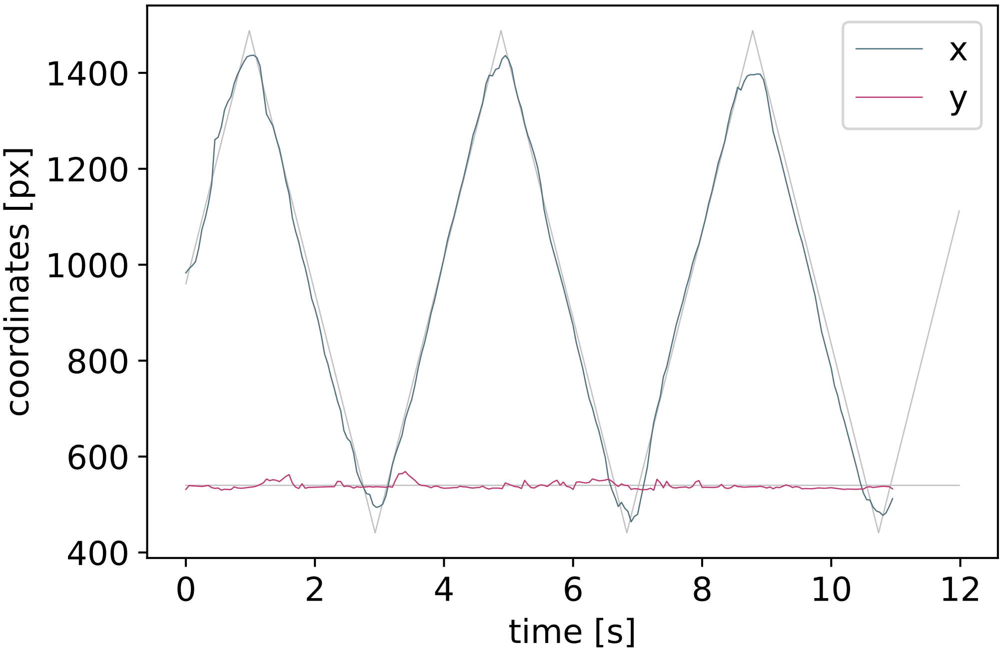


Figure A.41: velocity: 15 °/s, number of distractors: 0, axis: horizontal

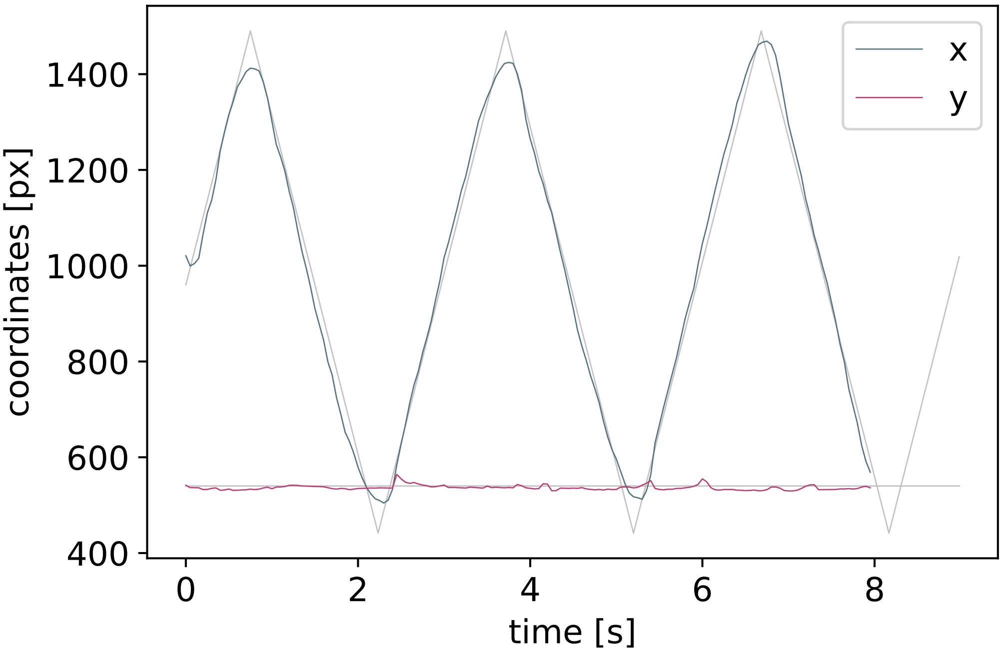


Figure A.42: velocity: 20 °/s, number of distractors: 0, axis: horizontal

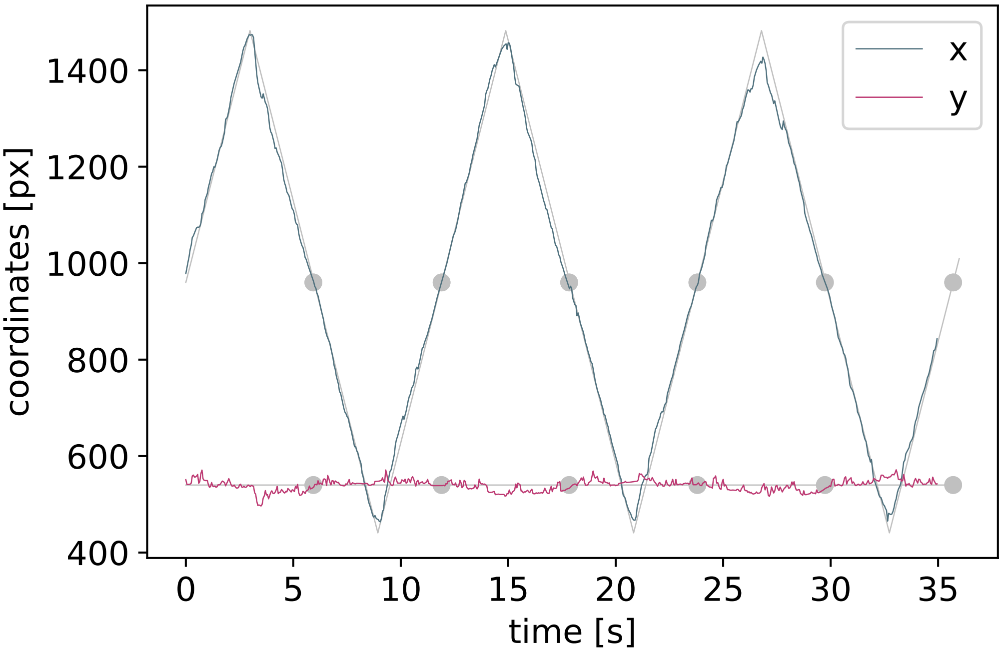


Figure A.43: velocity: 5 °/s, number of distractors: 1, axis: horizontal

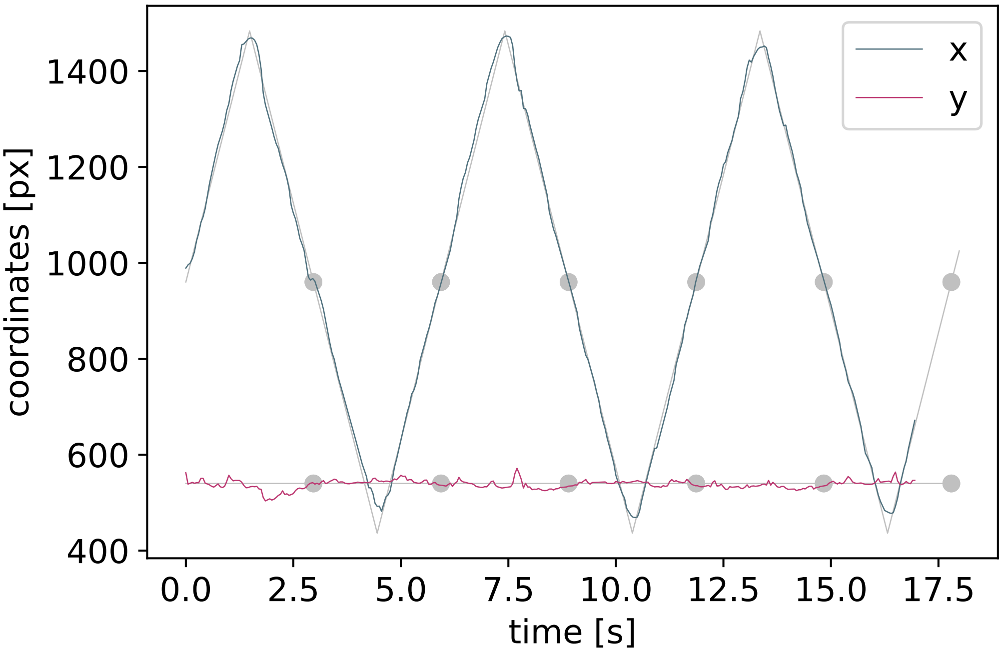


Figure A.44: velocity: 10 °/s, number of distractors: 1, axis: horizontal

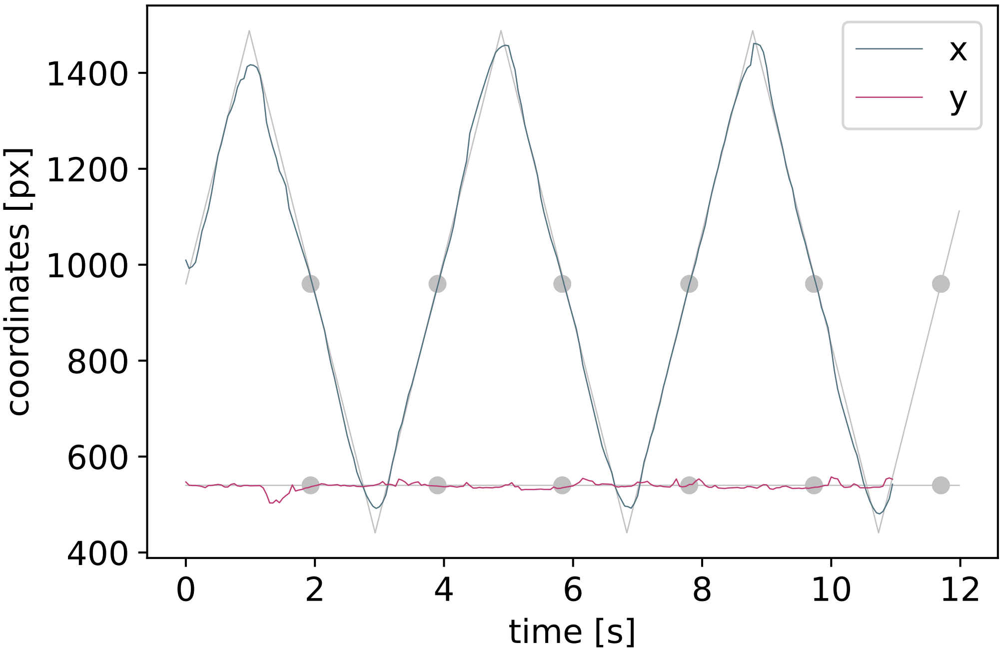


Figure A.45: velocity: 15 °/s, number of distractors: 1, axis: horizontal

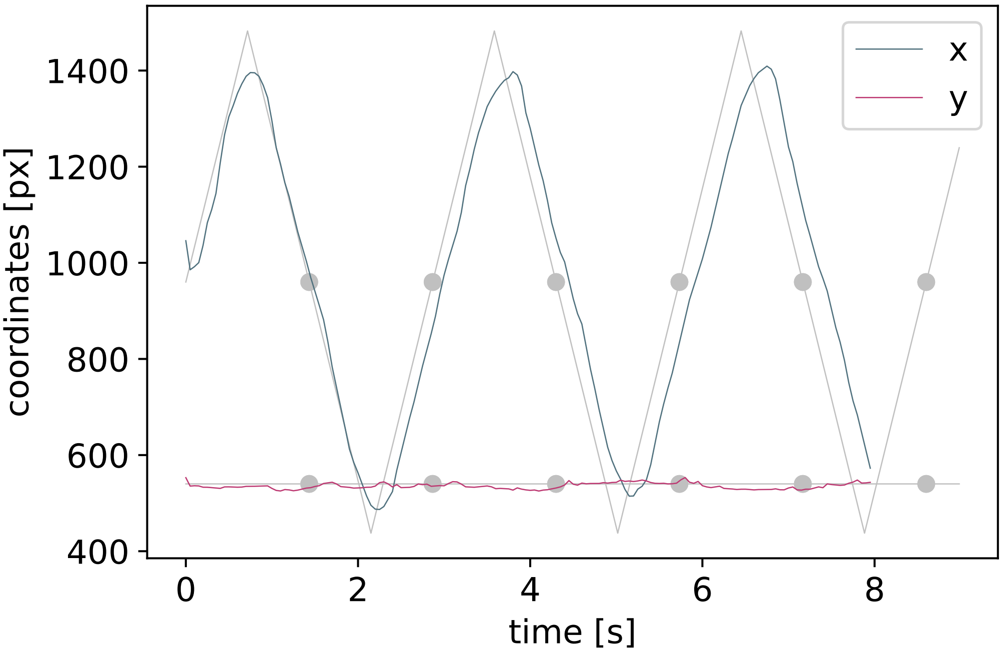


Figure A.46: velocity: 20 °/s, number of distractors: 1, axis: horizontal

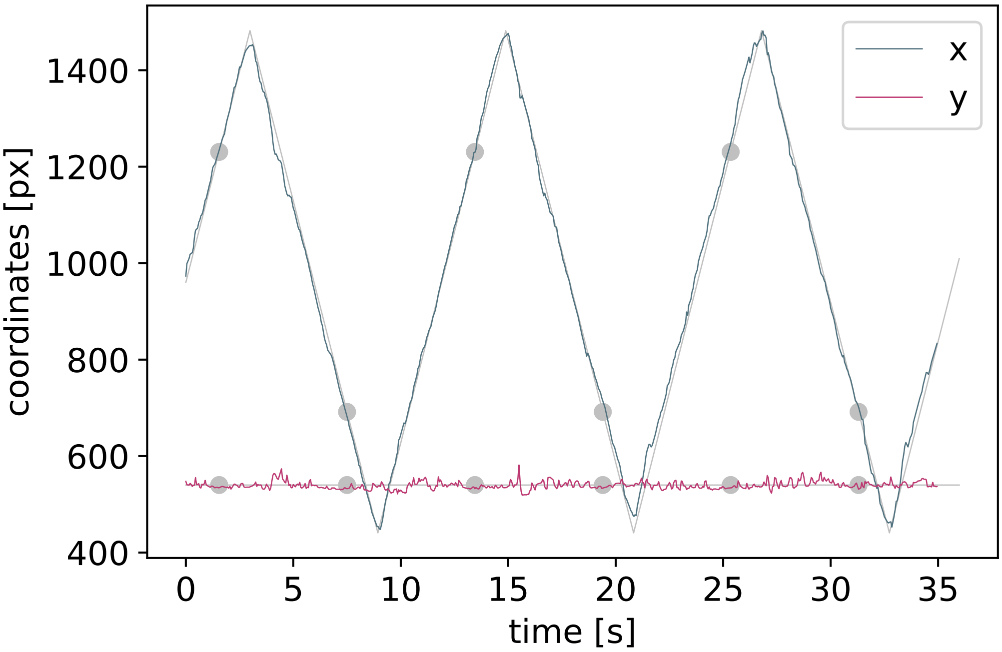


Figure A.47: velocity: 5 °/s, number of distractors: 2, axis: horizontal

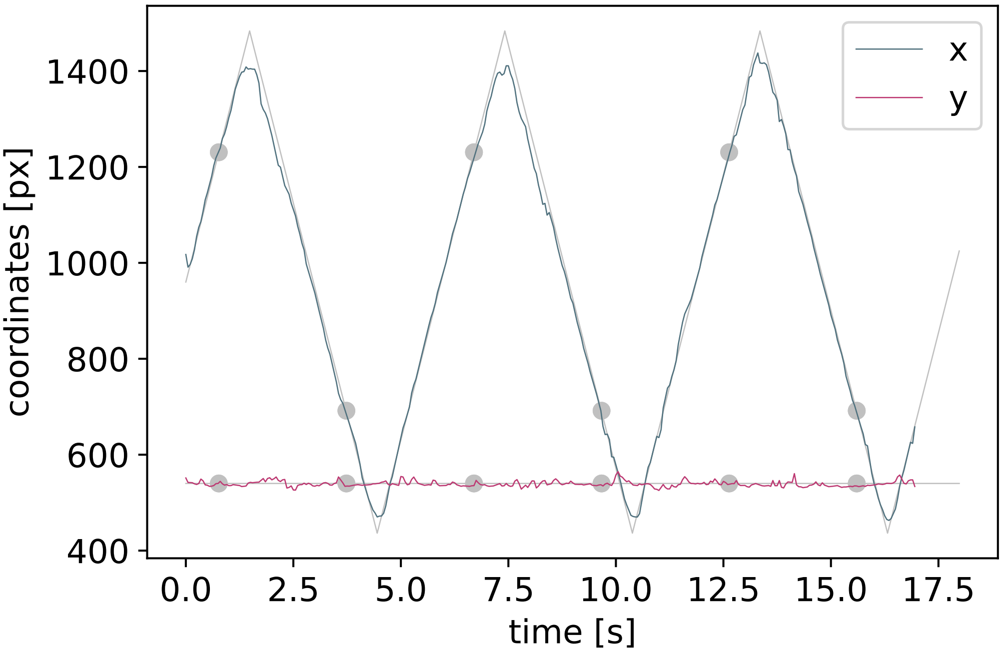


Figure A.48: velocity: 10 °/s, number of distractors: 2, axis: horizontal

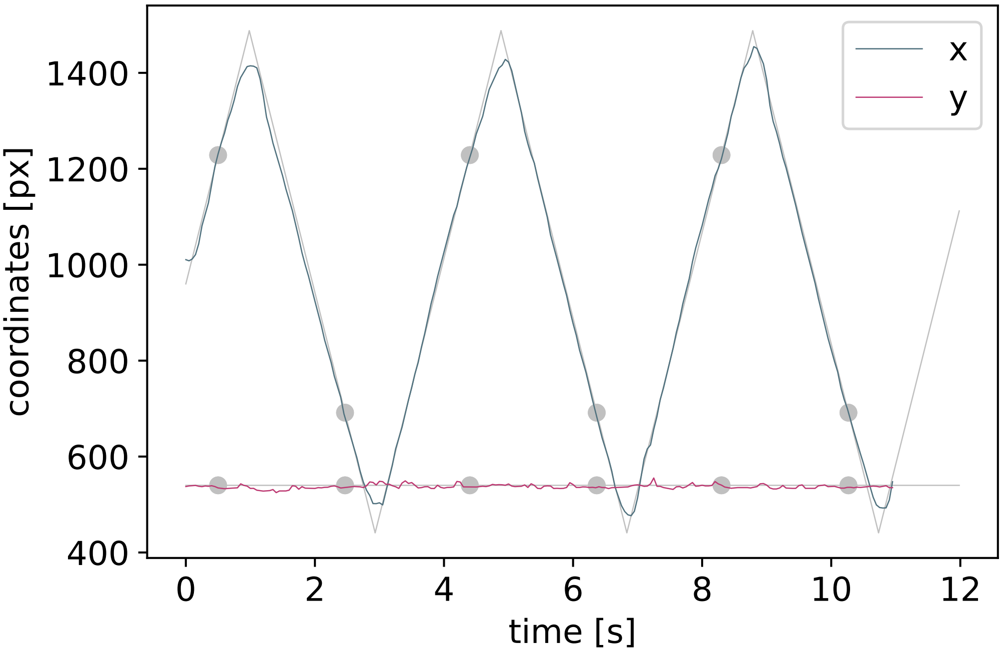


Figure A.49: velocity: 15 °/s, number of distractors: 2, axis: horizontal

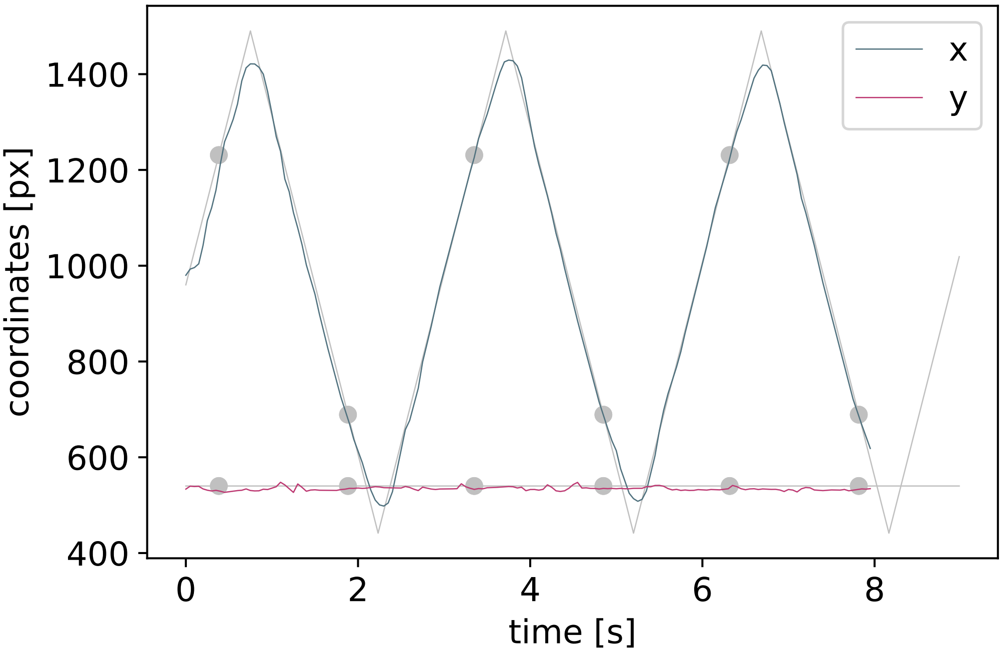


Figure A.50: velocity: 20 °/s, number of distractors: 2, axis: horizontal

A.4 AOI plots

This section contains the AOI plots. These show the AOIs every participant looked at, for each condition. As the first figure suggests, it is marked blue if the participant looked at the target, red if he looked at the first distractor and brown if he looked at the second one. For the intersection of multiple AOIs, this is marked black and the white space shows that no AOI was looked at. There are headings to facilitate finding the desired condition.

Figure A.51: Legend for all following plots.

Direction: bottom

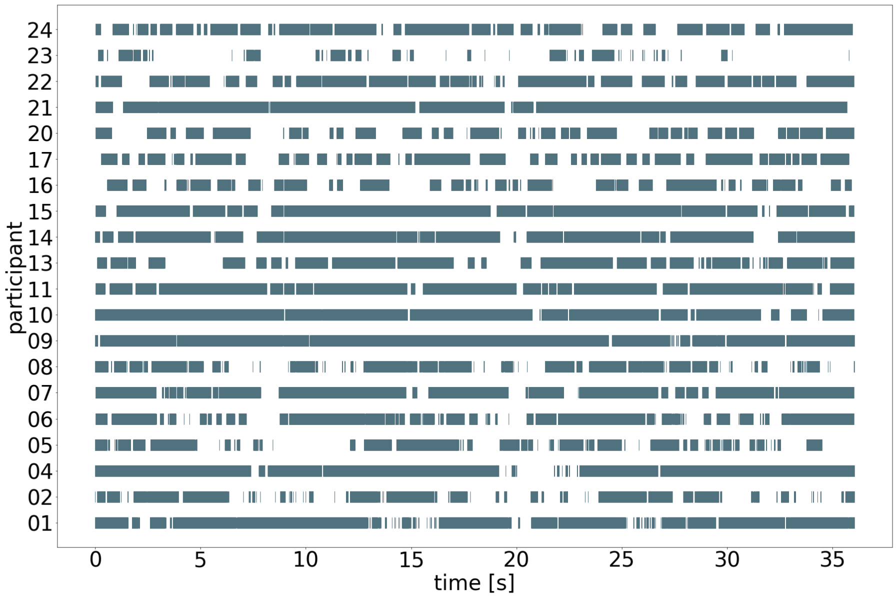


Figure A.52: velocity: 5 °/s, number of distractors: 0, direction: bottom

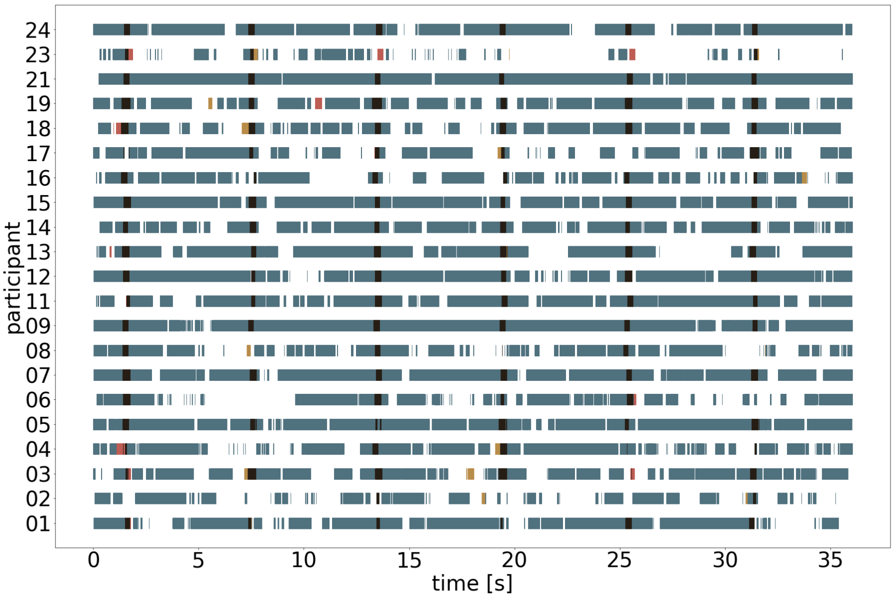


Figure A.53: velocity: 5 °/s, number of distractors: 2, direction: bottom

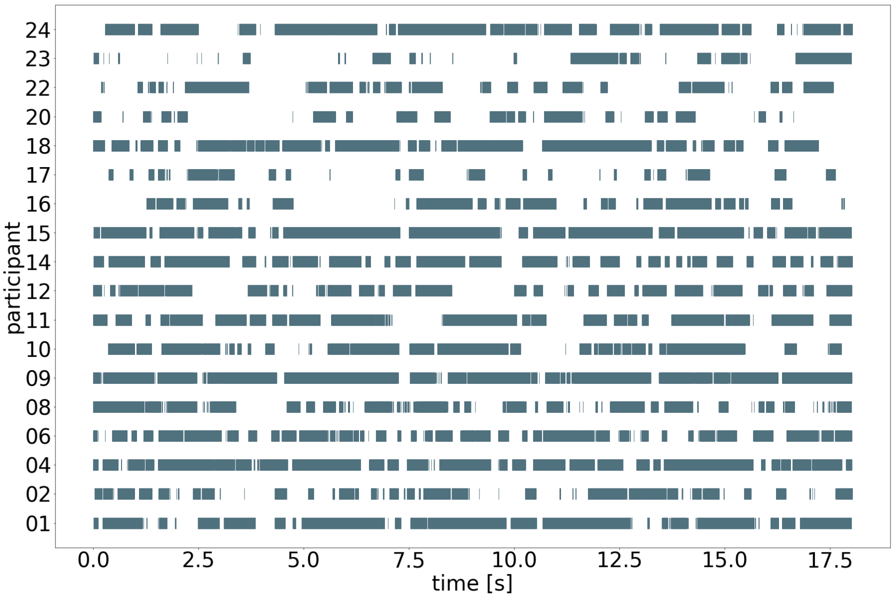


Figure A.54: velocity: 10 °/s, number of distractors: 0, direction: bottom

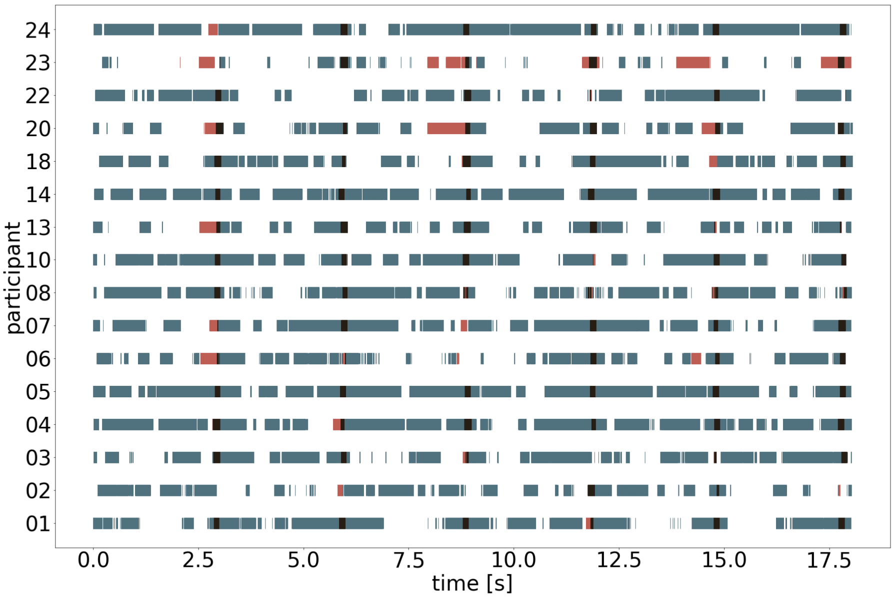


Figure A.55: velocity: 10 °/s, number of distractors: 1, direction: bottom

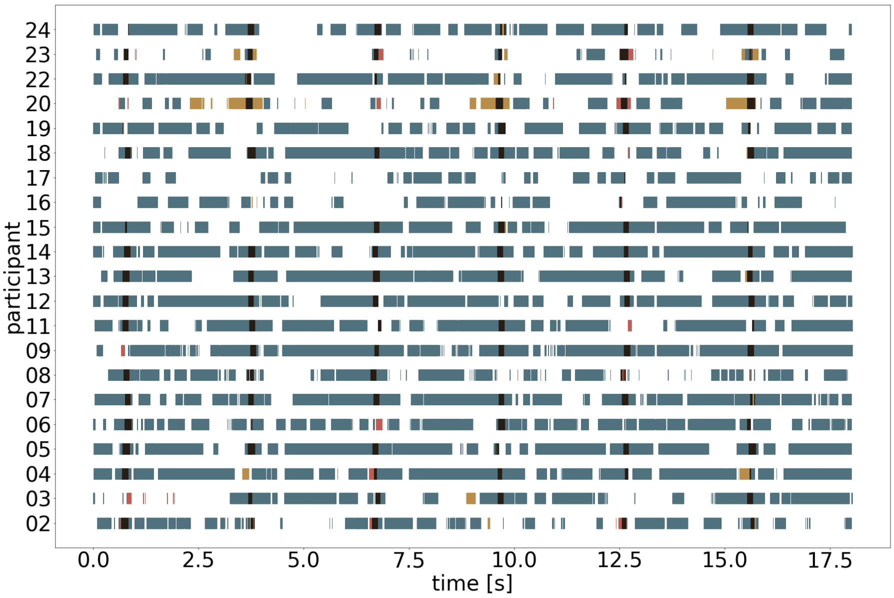


Figure A.56: velocity: 10 °/s, number of distractors: 2, direction: bottom

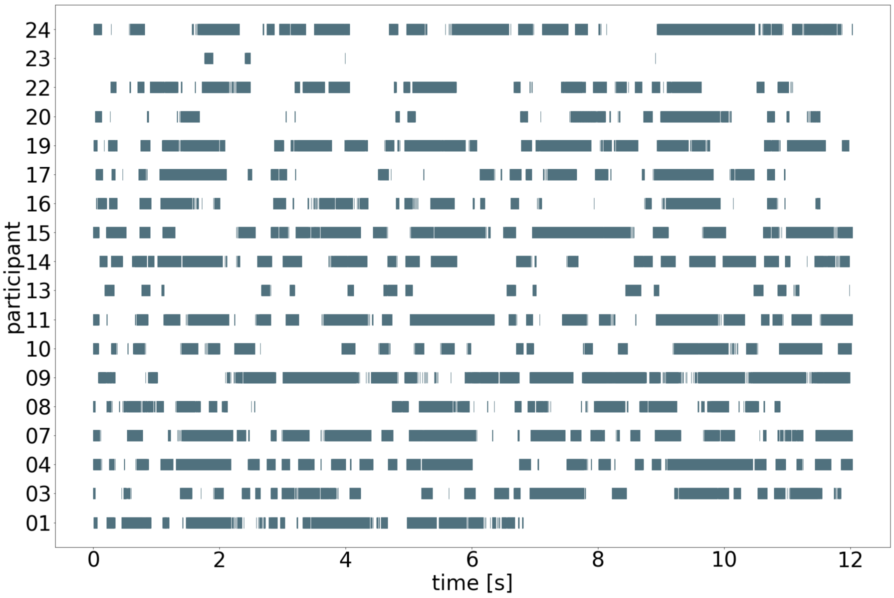


Figure A.57: velocity: 15 °/s, number of distractors: 0, direction: bottom

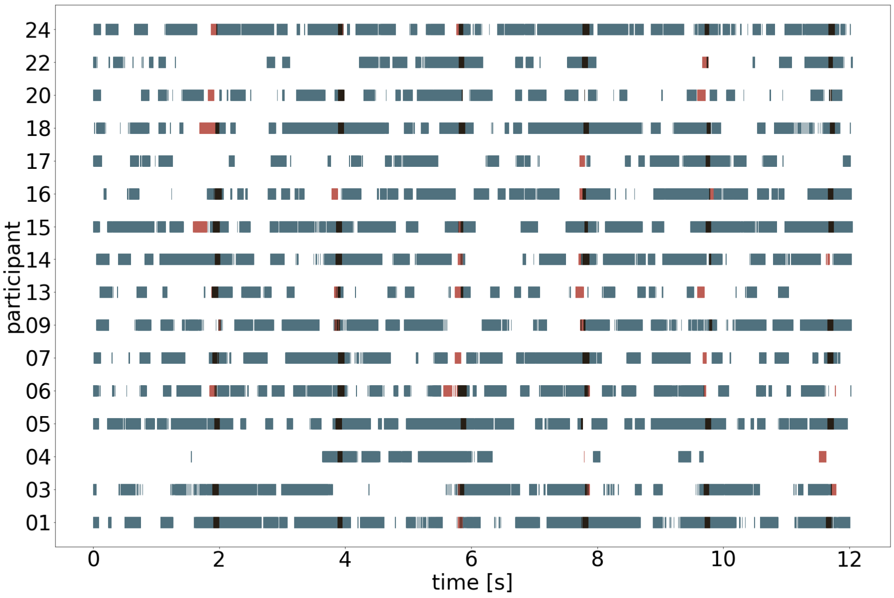


Figure A.58: velocity: 15 °/s, number of distractors: 1, direction: bottom

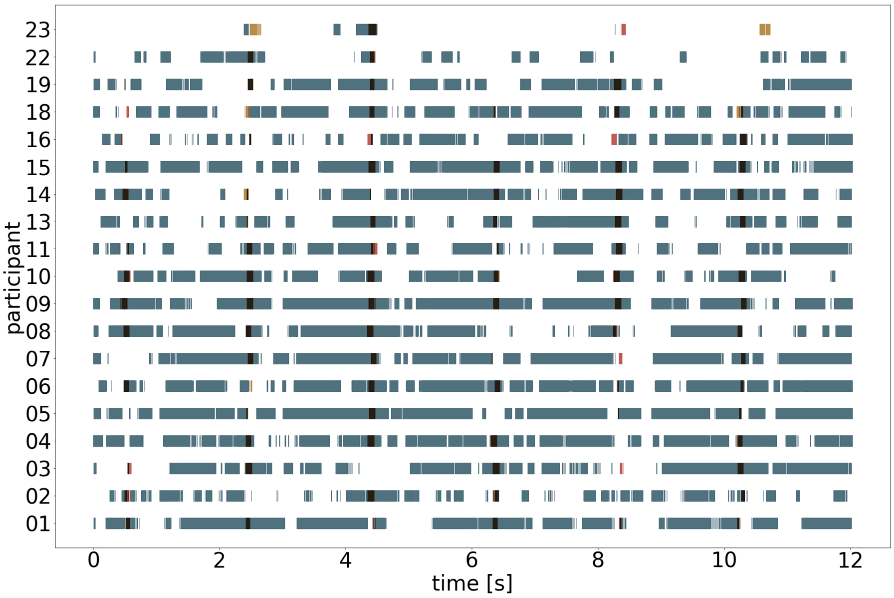


Figure A.59: velocity: 15 °/s, number of distractors: 2, direction: bottom

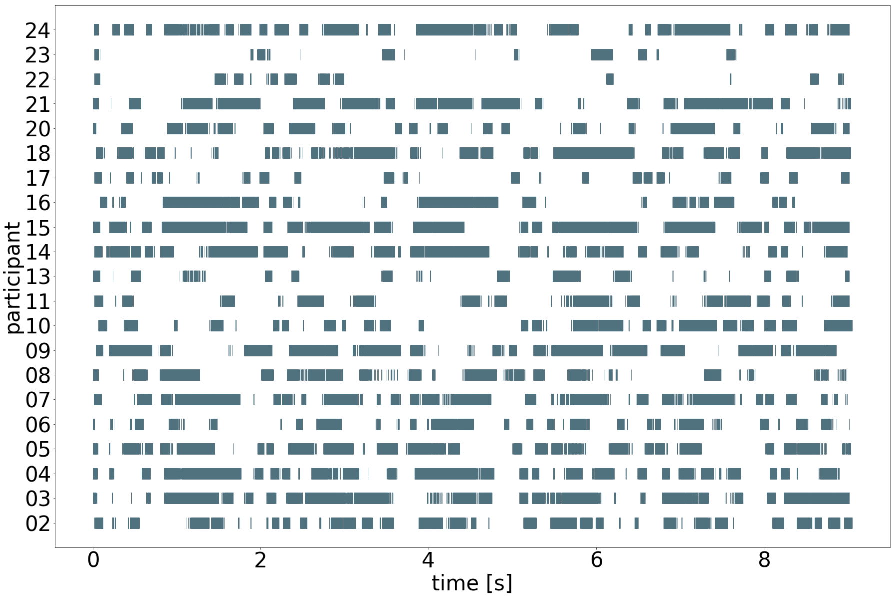


Figure A.60: velocity: 20 °/s, number of distractors: 0, direction: bottom

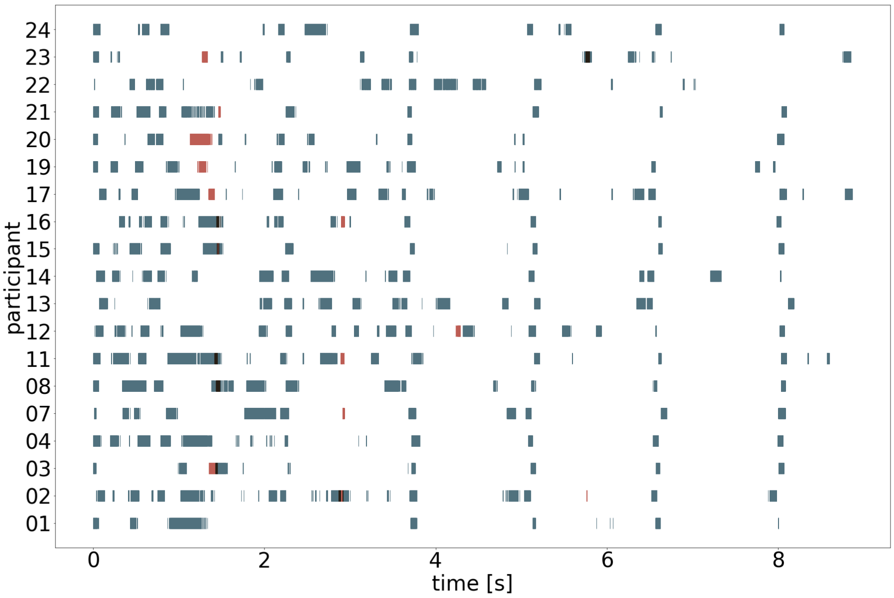


Figure A.61: velocity: 20 °/s, number of distractors: 1, direction: bottom

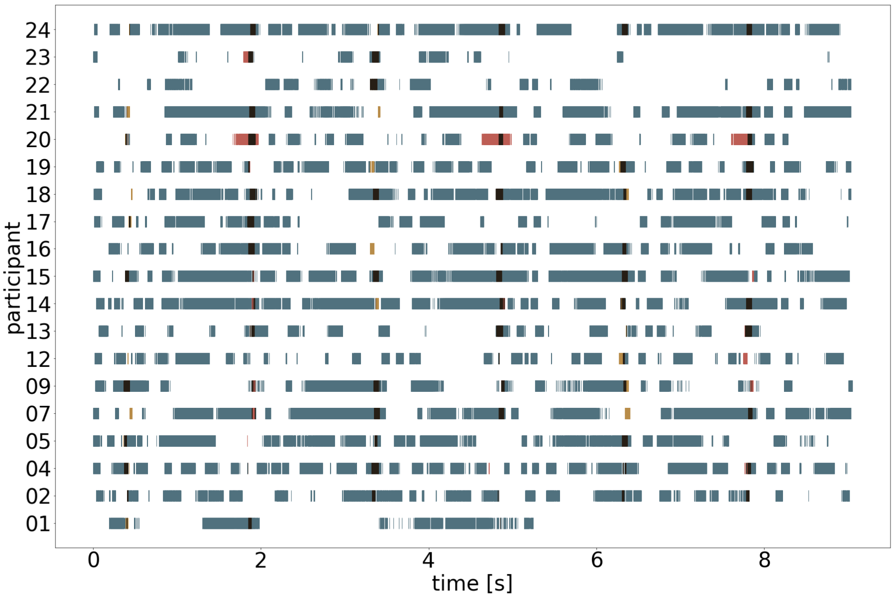


Figure A.62: velocity: 20 °/s, number of distractors: 2, direction: bottom

Direction: top

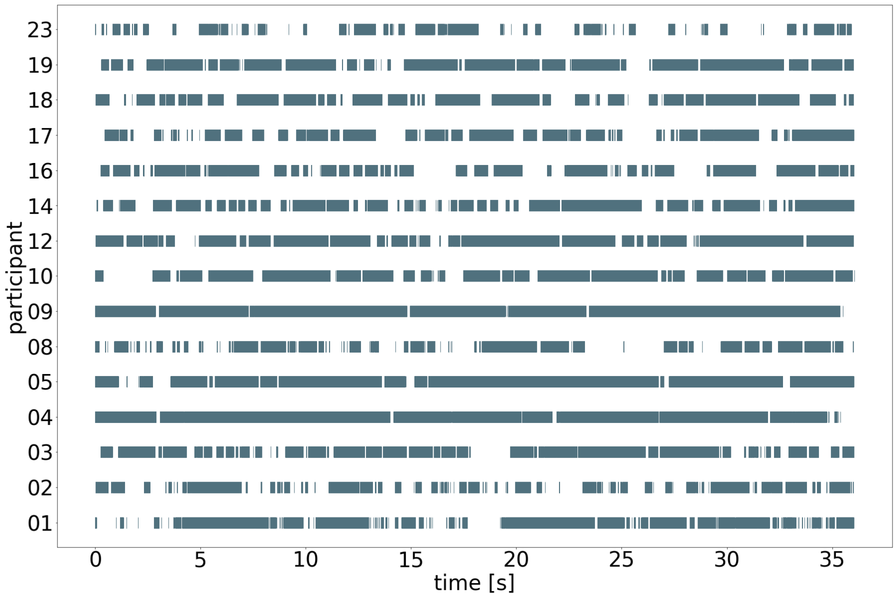


Figure A.63: velocity: 5 °/s, number of distractors: 0, direction: top

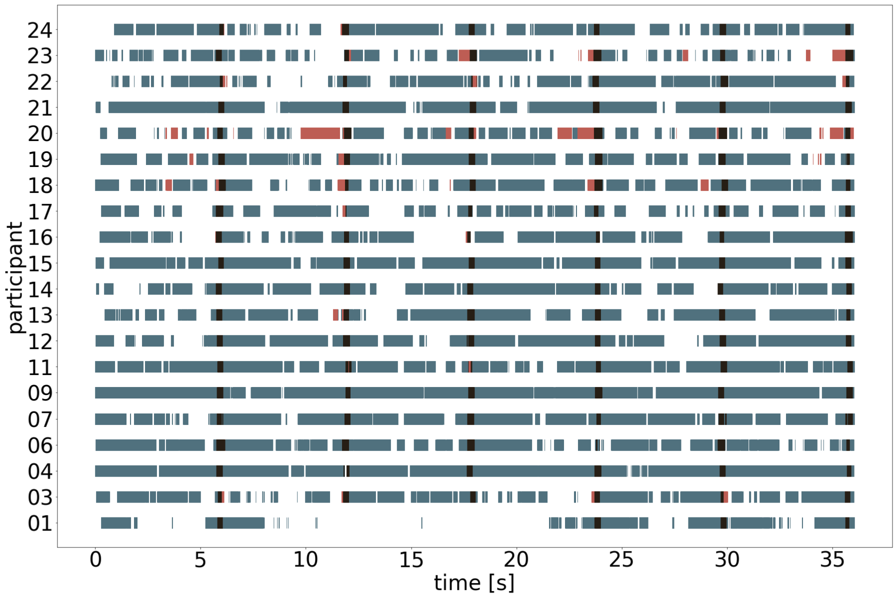


Figure A.64: velocity: 5 °/s, number of distractors: 1, direction: top

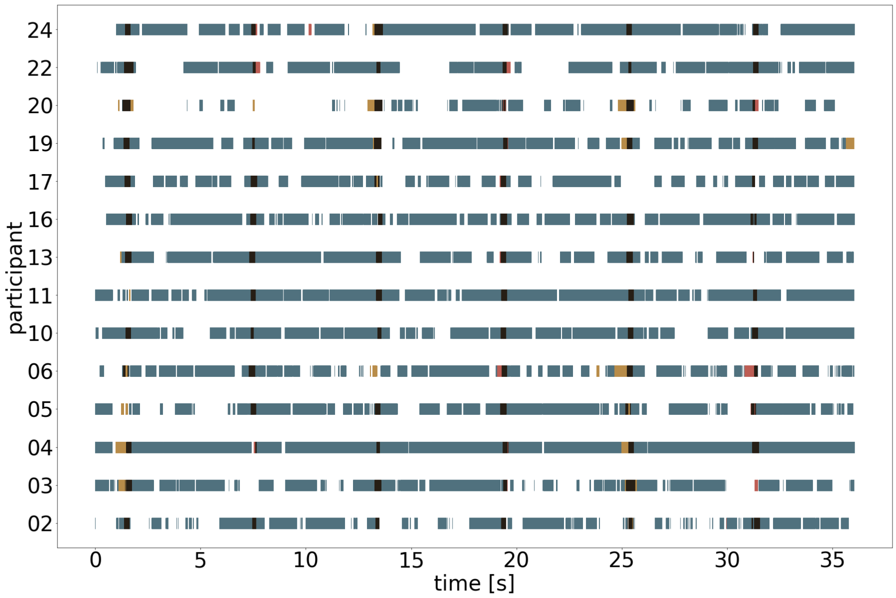


Figure A.65: velocity: 5 °/s, number of distractors: 2, direction: top

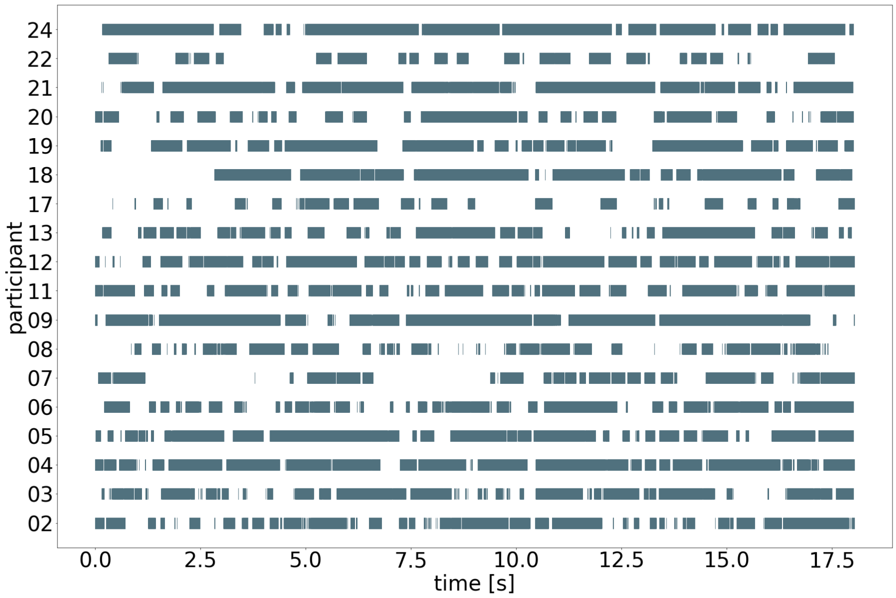


Figure A.66: velocity: 10 °/s, number of distractors: 0, direction: top

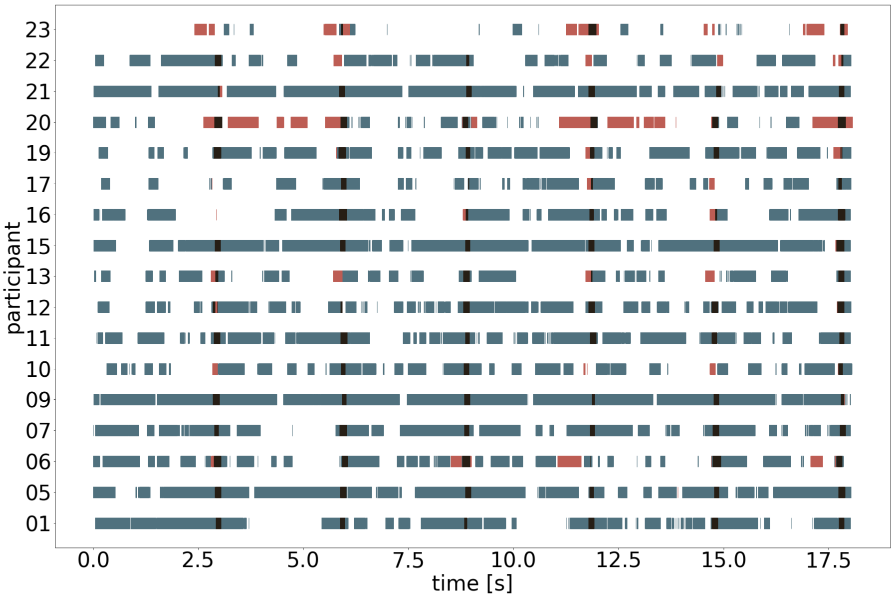


Figure A.67: velocity: 10 °/s, number of distractors: 1, direction: top

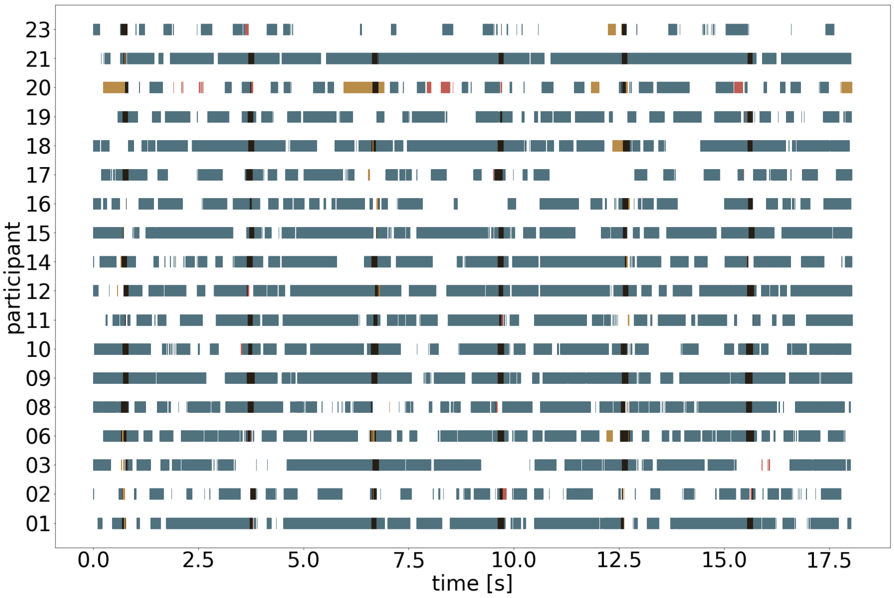


Figure A.68: velocity: 10 °/s, number of distractors: 2, direction: top

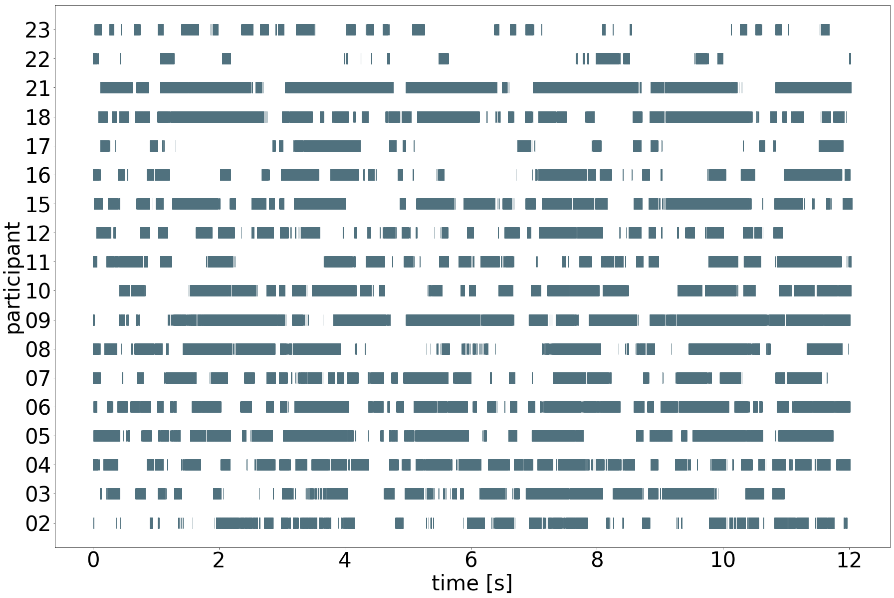


Figure A.69: velocity: 15 °/s, number of distractors: 0, direction: top

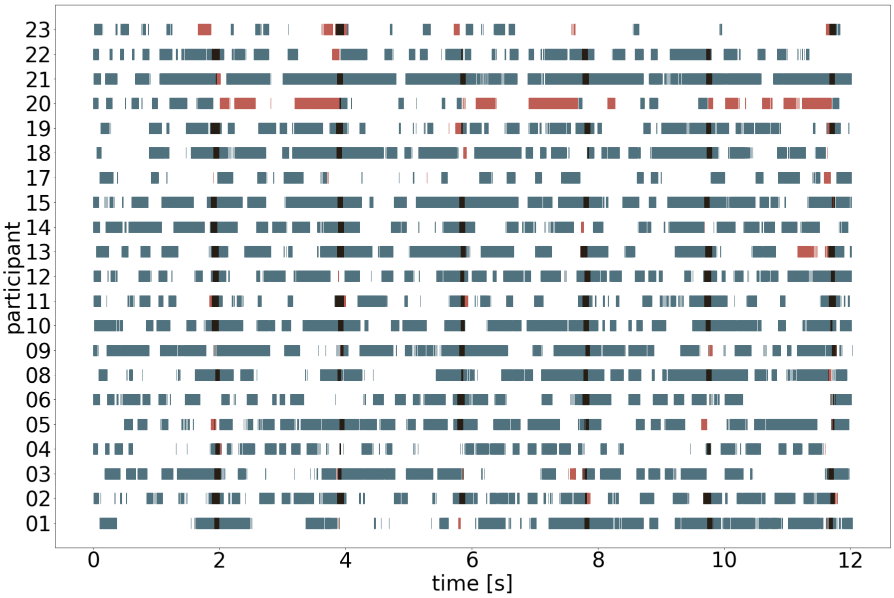


Figure A.70: velocity: 15 °/s, number of distractors: 1, direction: top

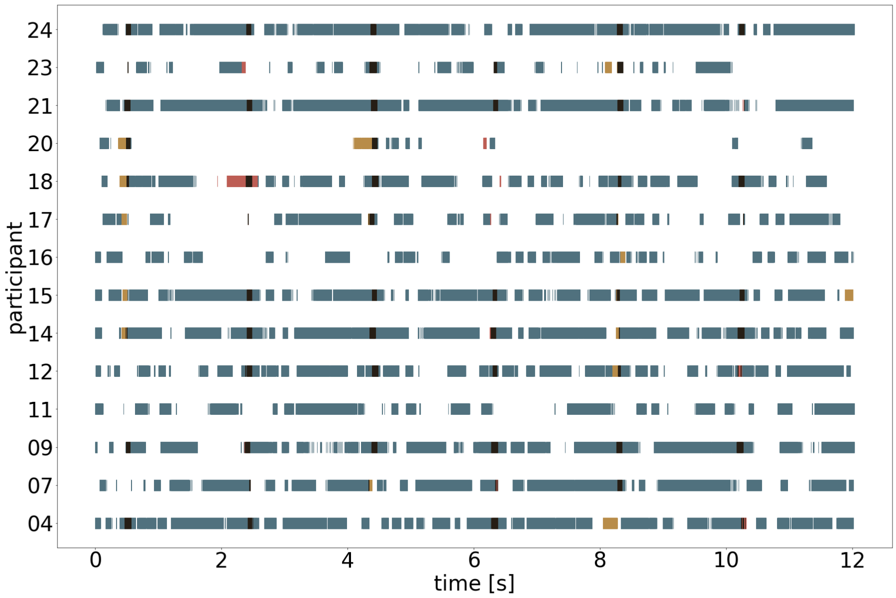


Figure A.71: velocity: 15 °/s, number of distractors: 2, direction: top

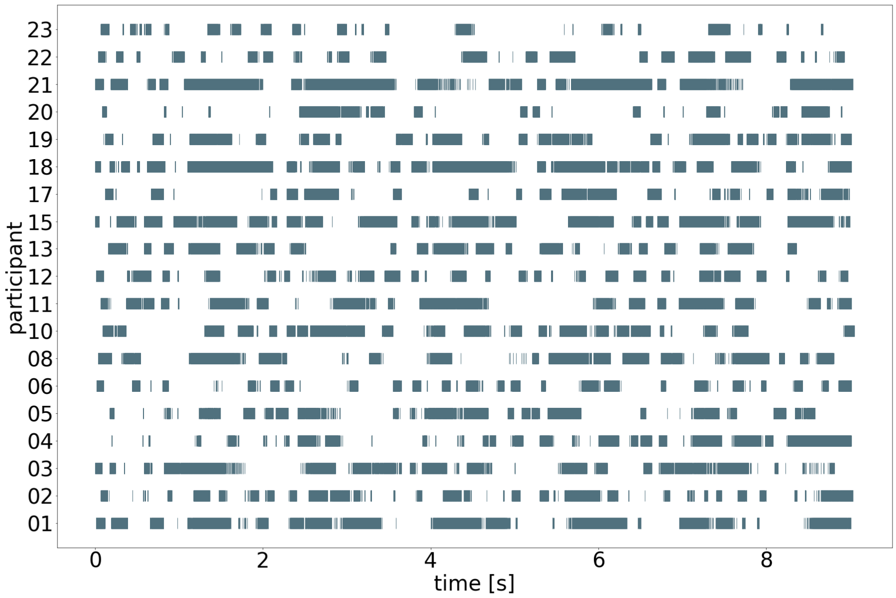


Figure A.72: velocity: 20 °/s, number of distractors: 0, direction: top

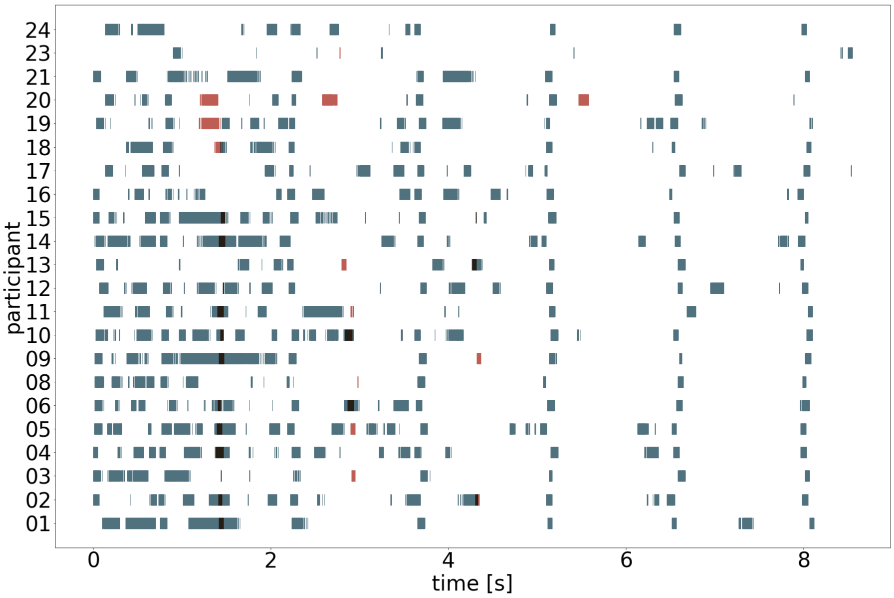


Figure A.73: velocity: 20 °/s, number of distractors: 1, direction: top

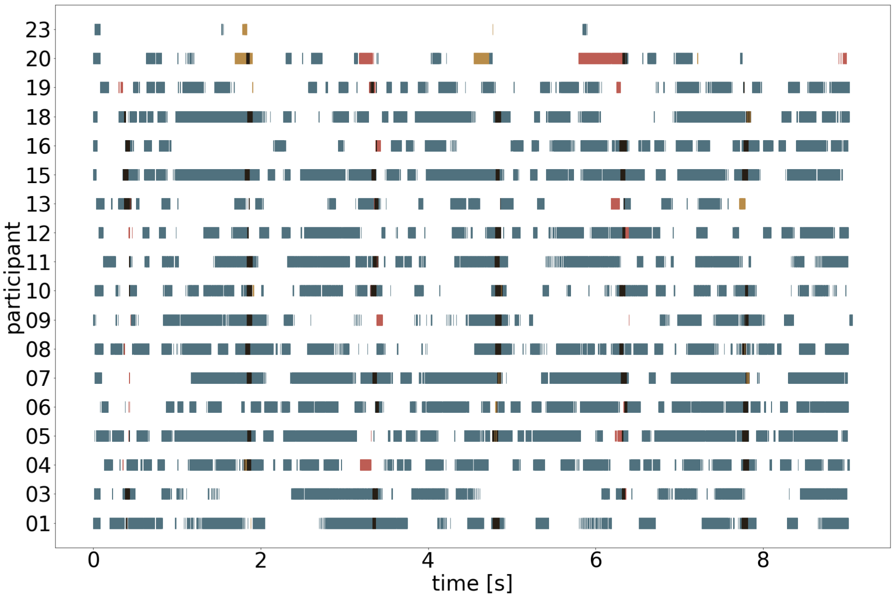


Figure A.74: velocity: 20 °/s, number of distractors: 2, direction: top

Direction: left

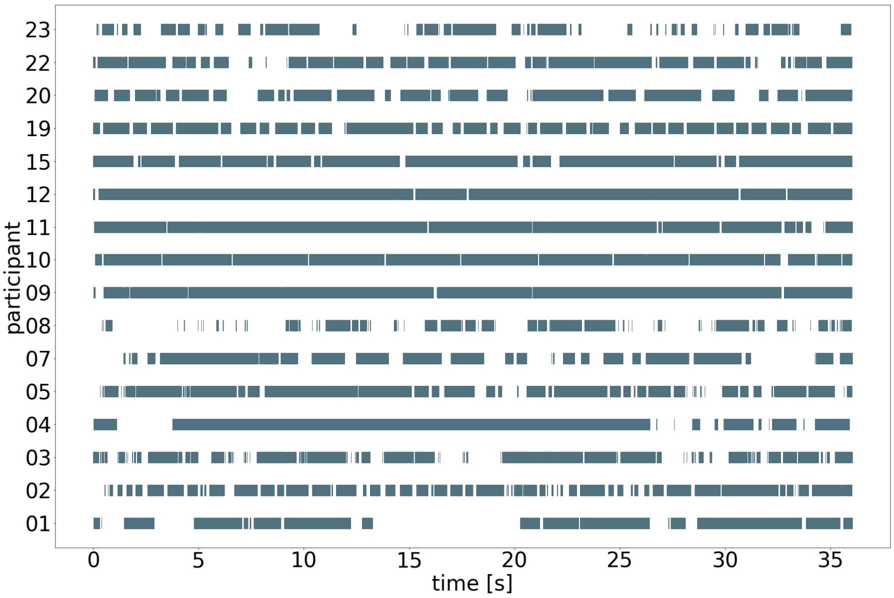


Figure A.75: velocity: 5 °/s, number of distractors: 0, direction: left

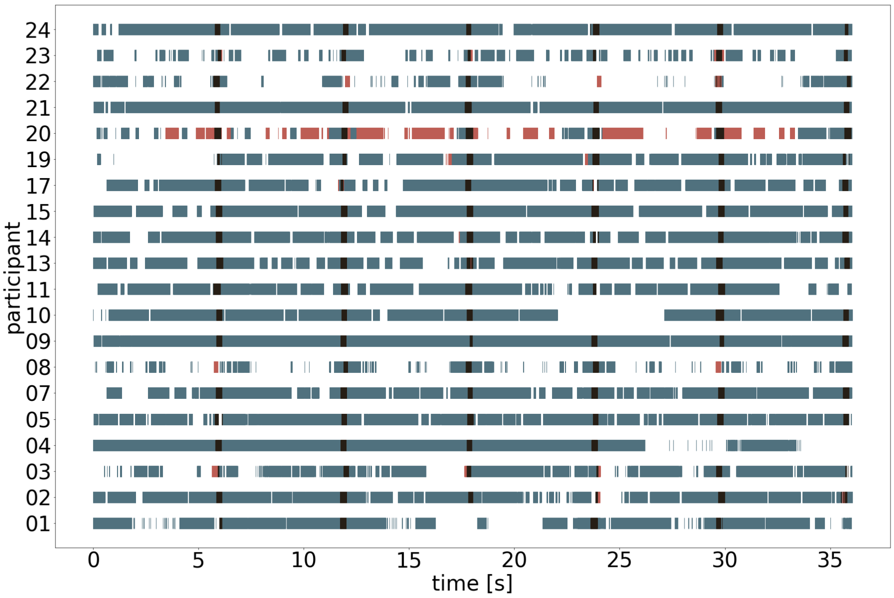


Figure A.76: velocity: 5 °/s, number of distractors: 1, direction: left

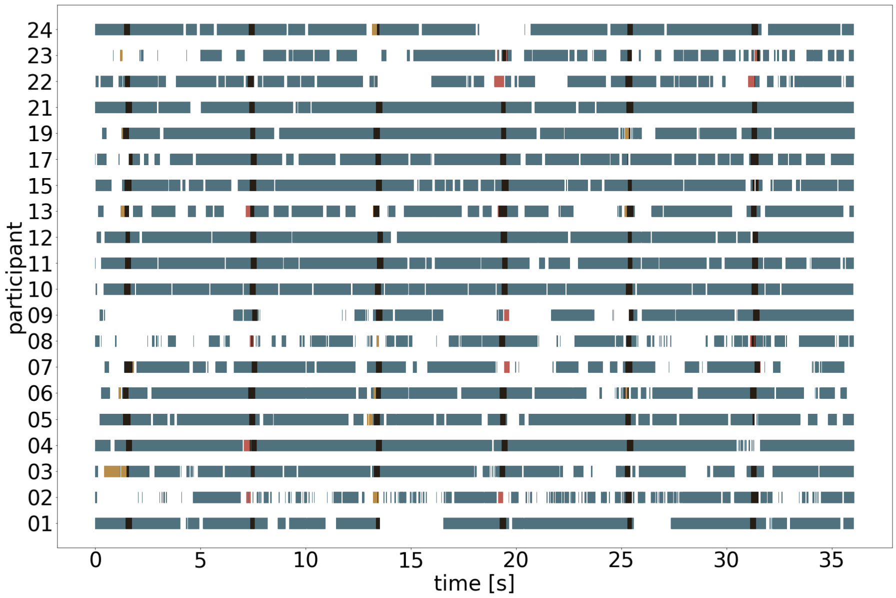


Figure A.77: velocity: 5 °/s, number of distractors: 2, direction: left

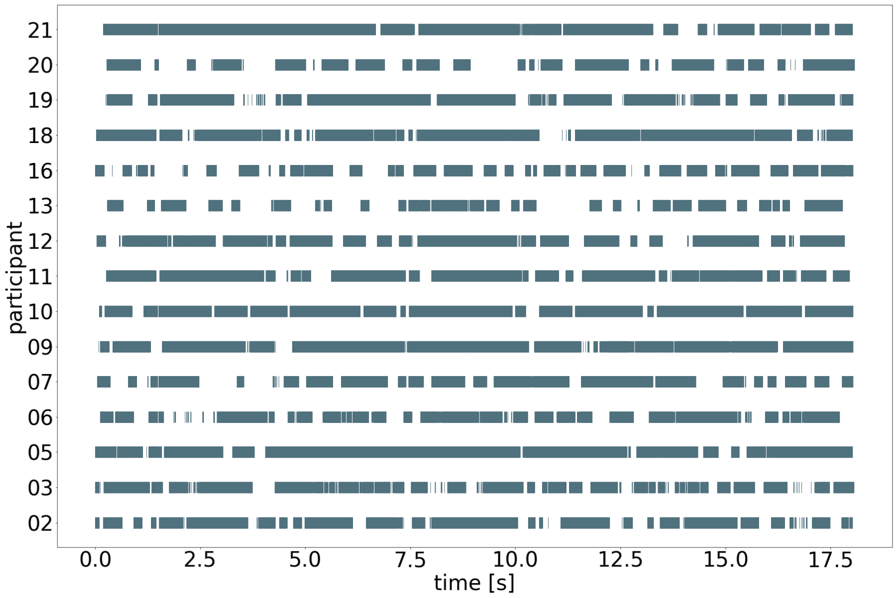


Figure A.78: velocity: 10 °/s, number of distractors: 0, direction: left

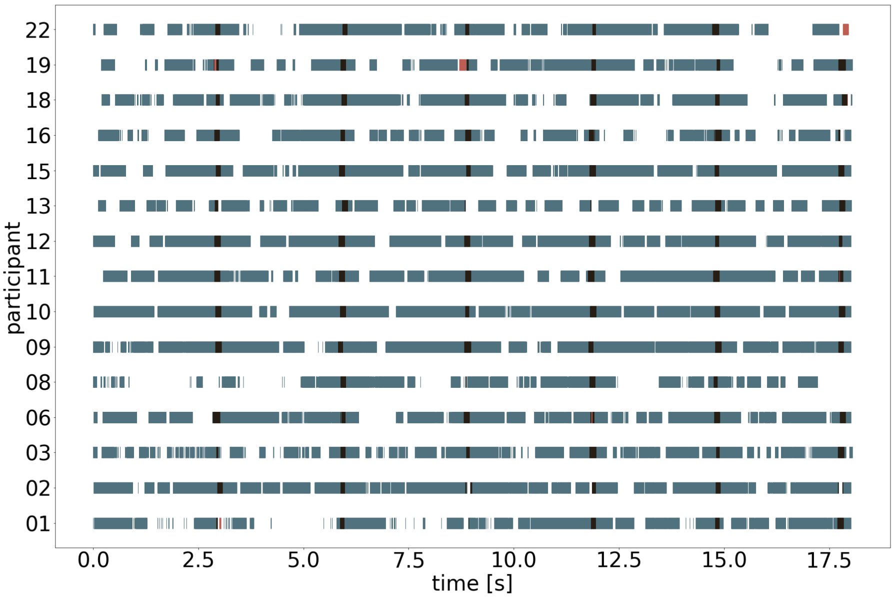


Figure A.79: velocity: 10 °/s, number of distractors: 1, direction: left

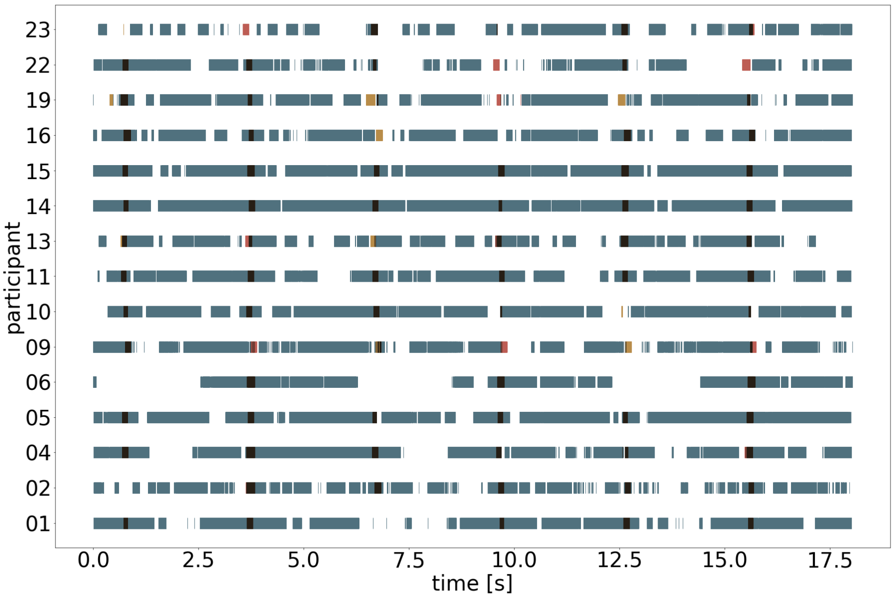


Figure A.80: velocity: 10 °/s, number of distractors: 2, direction: left

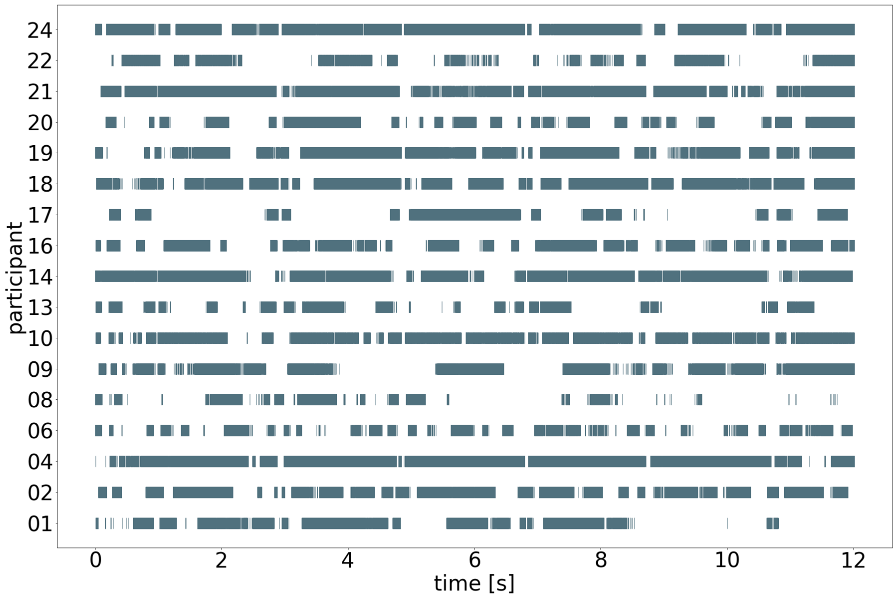


Figure A.81: velocity: 15 °/s, number of distractors: 0, direction: left

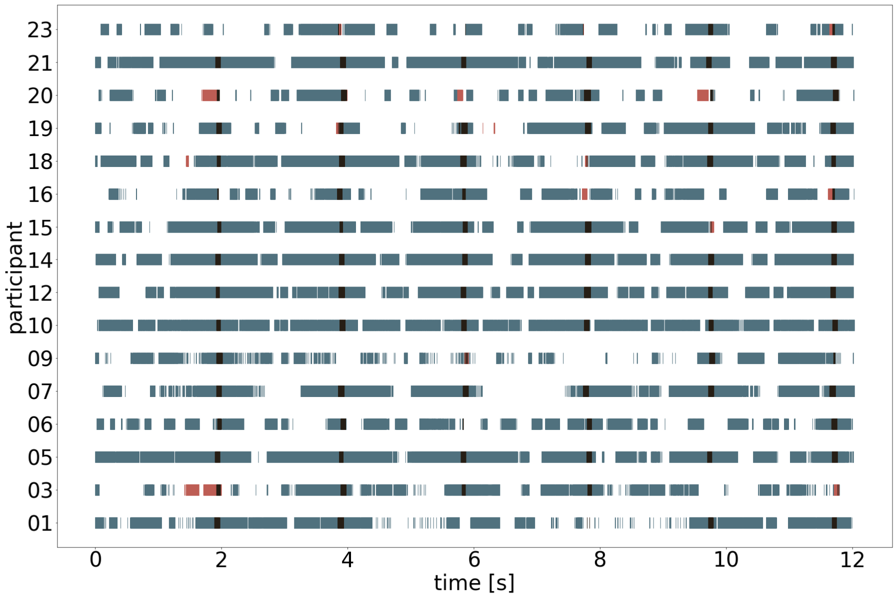


Figure A.82: velocity: 15 °/s, number of distractors: 1, direction: left

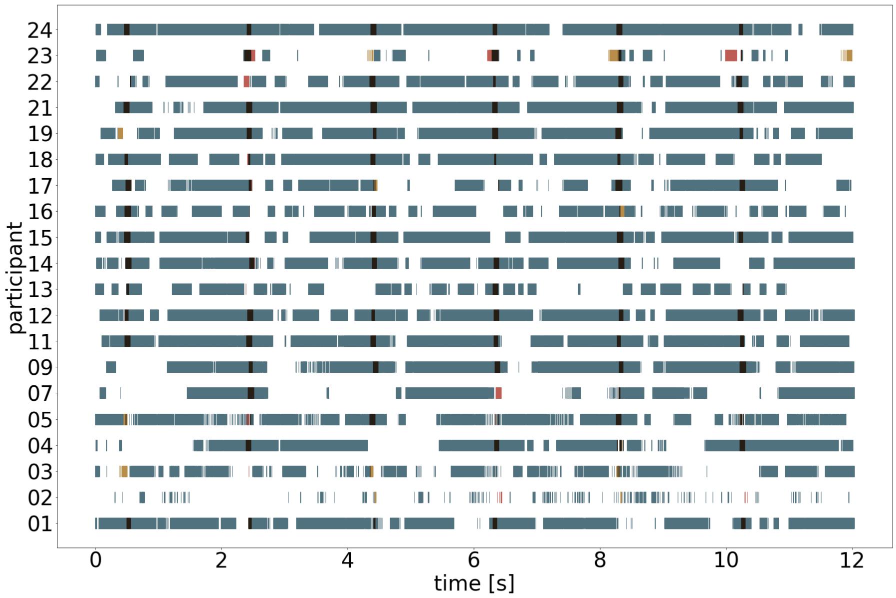


Figure A.83: velocity: 15 °/s, number of distractors: 2, direction: left

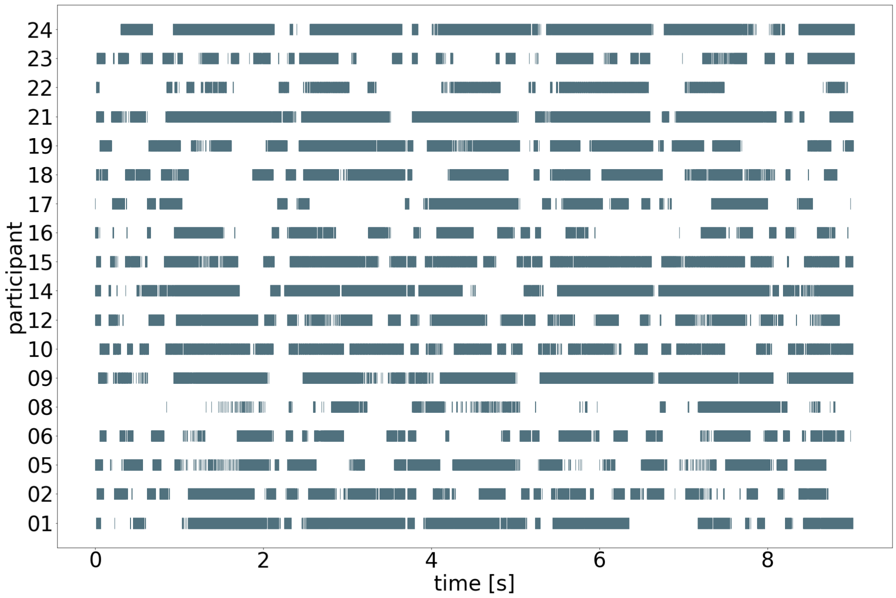


Figure A.84: velocity: 20 °/s, number of distractors: 0, direction: left

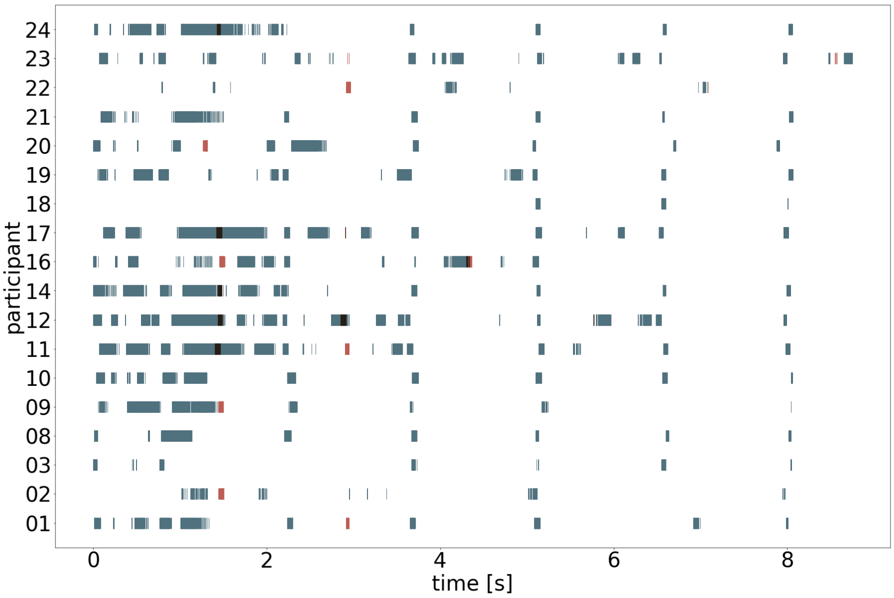


Figure A.85: velocity: 20 °/s, number of distractors: 1, direction: left

Direction: right

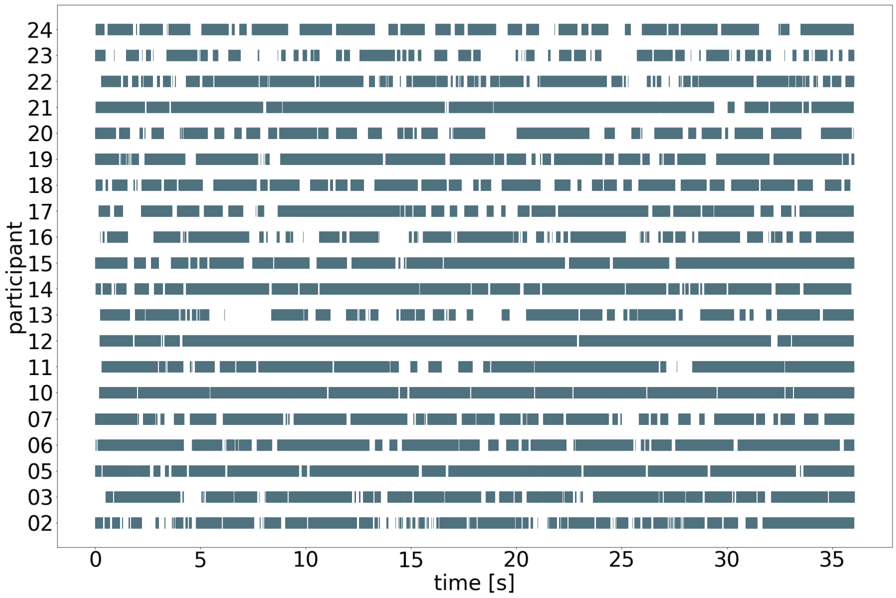


Figure A.86: velocity: 5 °/s, number of distractors: 0, direction: right

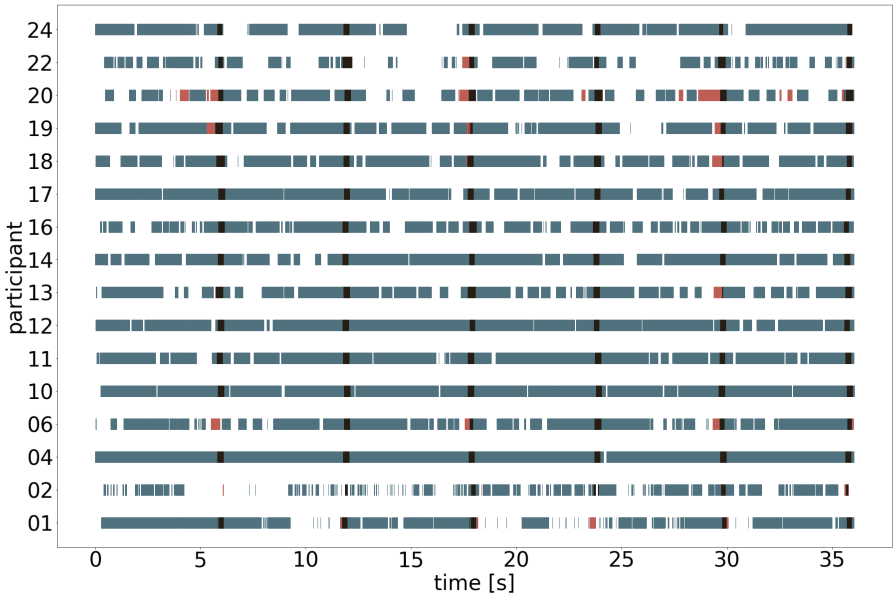


Figure A.87: velocity: 5 °/s, number of distractors: 1, direction: right

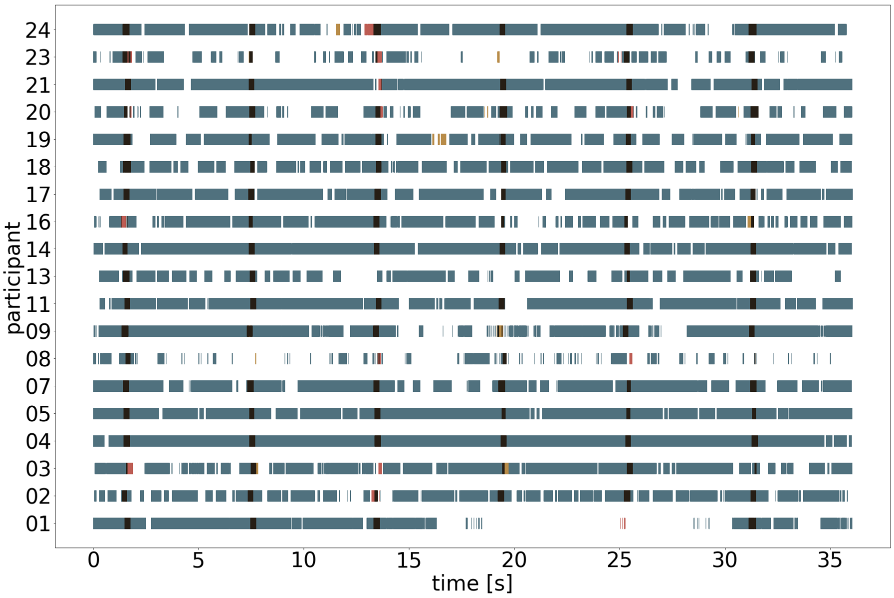


Figure A.88: velocity: 5 °/s, number of distractors: 2, direction: right

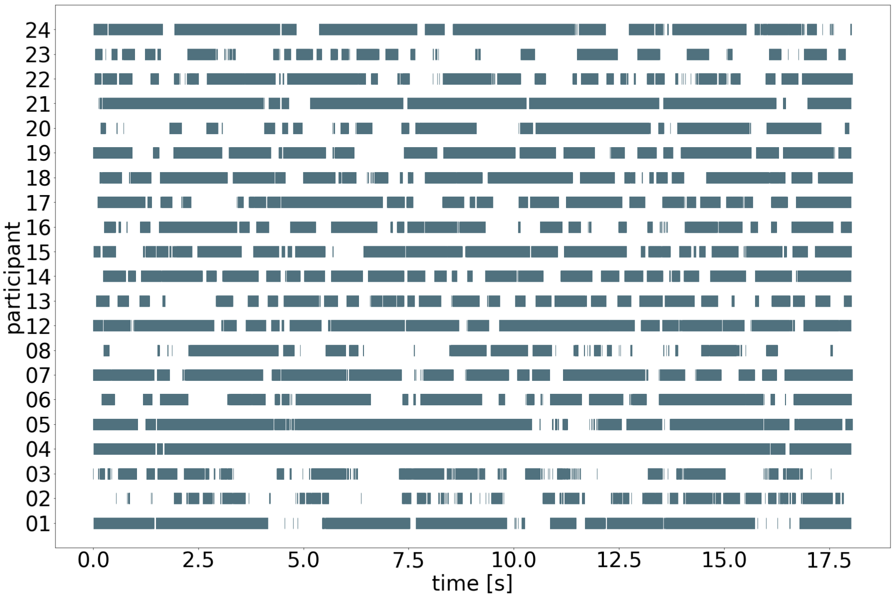


Figure A.89: velocity: 10 °/s, number of distractors: 0, direction: right

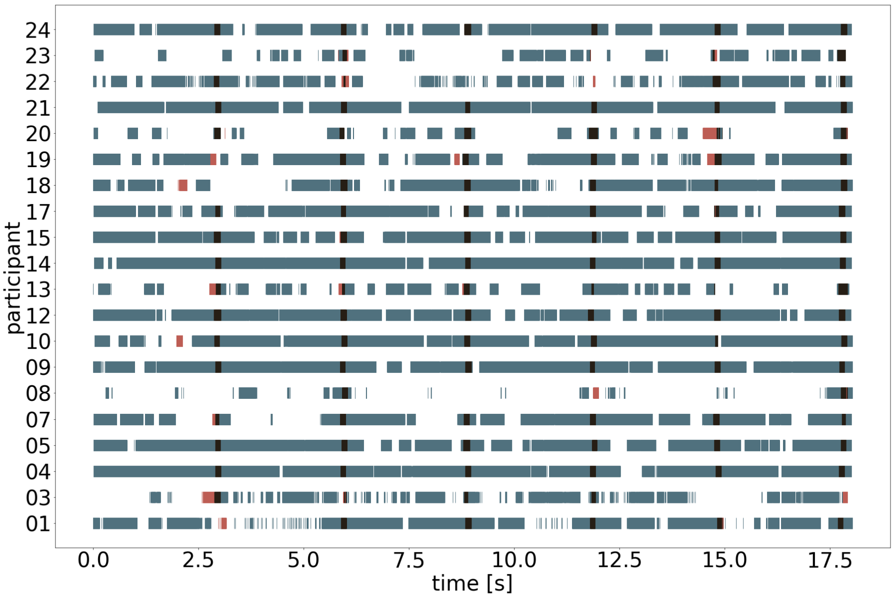


Figure A.90: velocity: 10 °/s, number of distractors: 1, direction: right

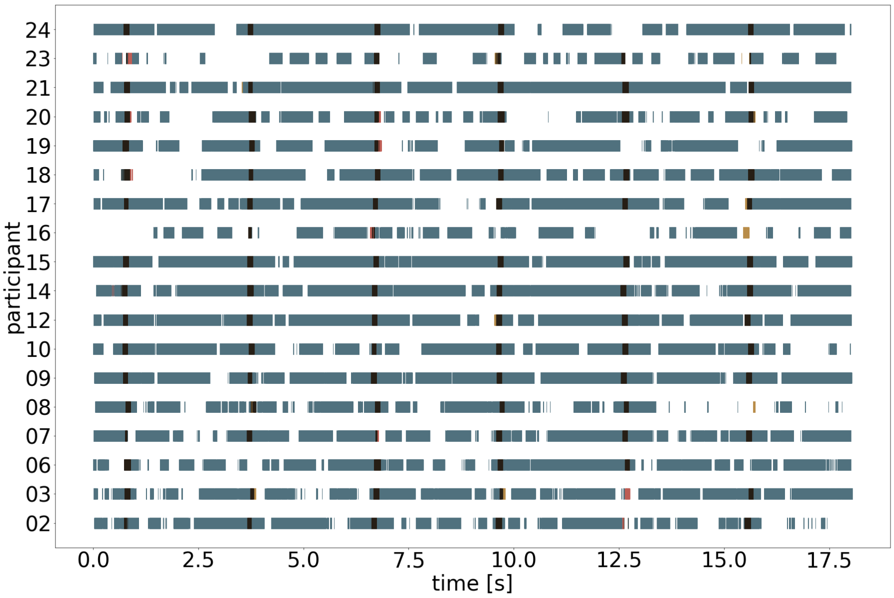


Figure A.91: velocity: 10 °/s, number of distractors: 2, direction: right

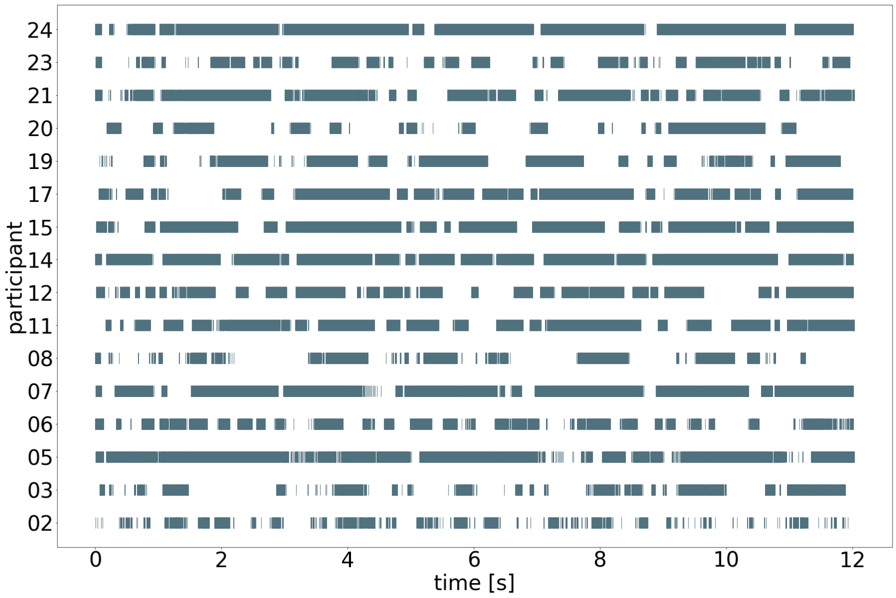


Figure A.92: velocity: 15 °/s, number of distractors: 0, direction: right

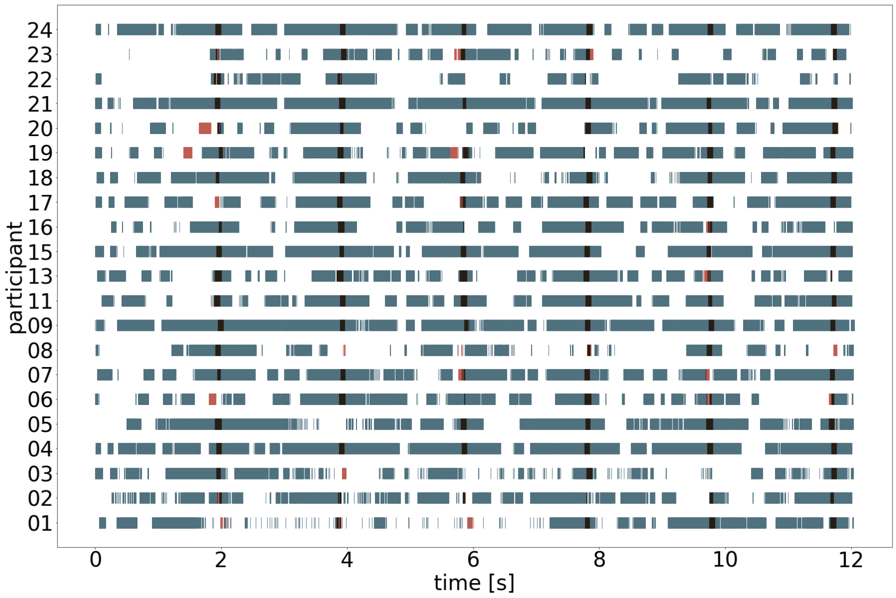


Figure A.93: velocity: 15 °/s, number of distractors: 1, direction: right

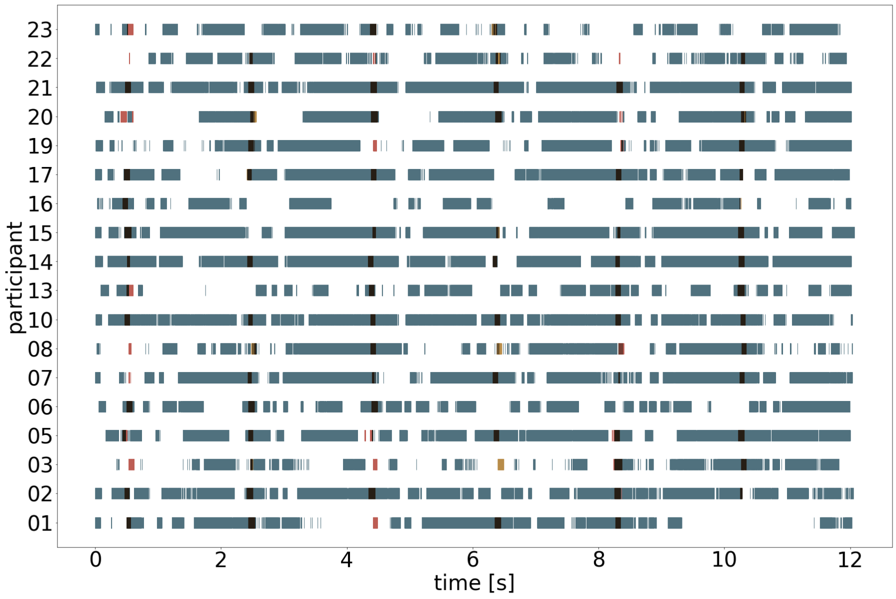


Figure A.94: velocity: 15 °/s, number of distractors: 2, direction: right

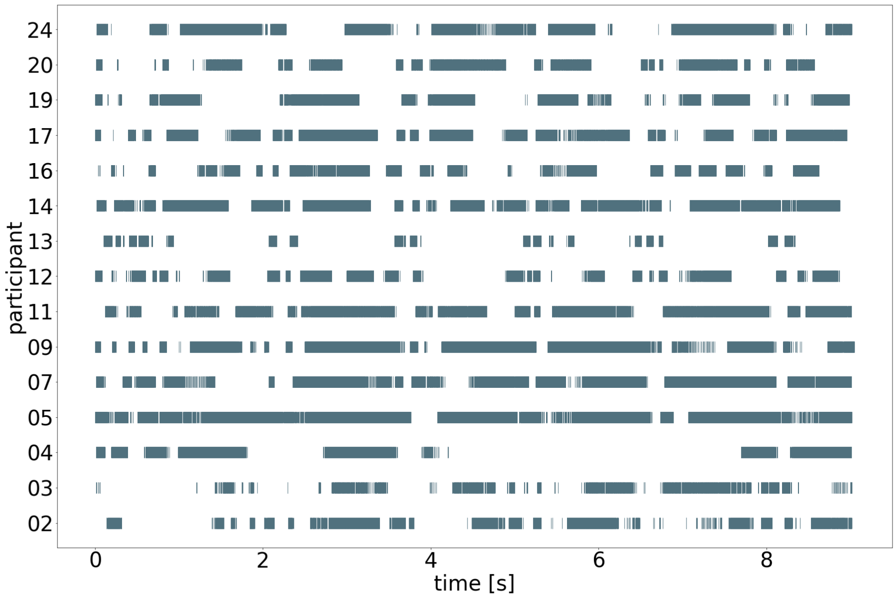


Figure A.95: velocity: 20 °/s, number of distractors: 0, direction: right

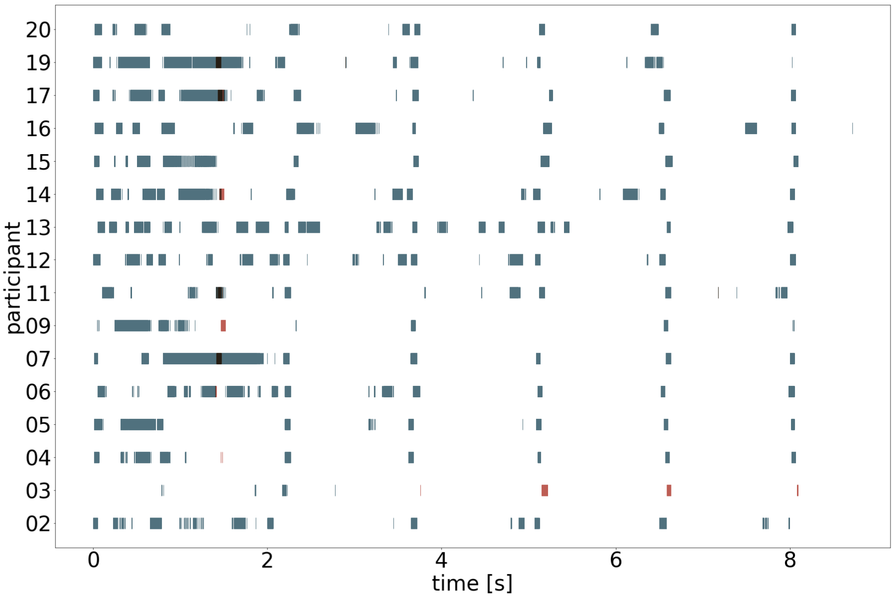


Figure A.96: velocity: 20 °/s, number of distractors: 1, direction: right

Declaration

I hereby declare that the work presented in this thesis is entirely my own and that I did not use any other sources and references than the listed ones. I have marked all direct or indirect statements from other sources contained therein as quotations. Neither this work nor significant parts of it were part of another examination procedure. I have not published this work in whole or in part before. The electronic copy is consistent with all submitted copies.

place, date, signature