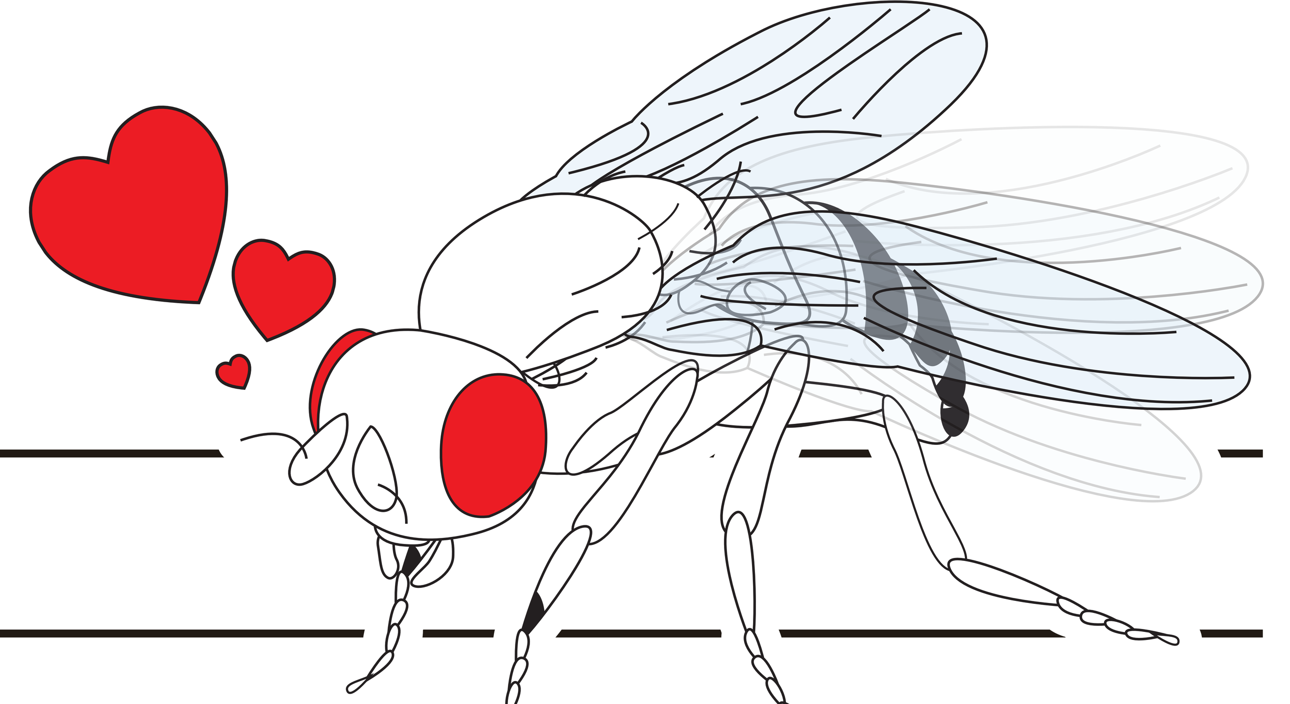
Understanding the quick control of “love” directed locomotion in fruit fly



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SUMMARY

During courtship, the male Drosophila melanogaster chases the female to captivate her for copulation. While chasing, he continuously minimizes the angle between his body axis and the female position (error angle). Interestingly, the male has been shown to rotate his body to correct for the error angle within just 24ms. This is fast, considering that it takes an average of 20-30ms for visual information to reach the brain and around 10ms for an action command from the brain to be executed. How the male corrects the error angle with such temporal efficiency during courtship chasing is not understood.

To tackle this problem, we used a paradigm where the male engages in the pursuit of a magnet following a pre-determined path. Under this controlled scenario we observed that the male accounts for changes in error angle provoked by the magnet motion not only with rotations, but also with translation. Furthermore, we observed that the translation of the male anticipates the change in error angle induced by the magnet motion. The amount of error angle induced by the magnet motion not accounted by translation is then accommodated, with a small delay of around 40ms, by rotations.

The contribution of translational motion and anticipatory capabilities shown by the male in response to the changes in error angle induced by the magnet motion, if used during real female chasing, could explain the fast male responses during courtship.

The Male Quickly Rotates His Body to Face the Female Position

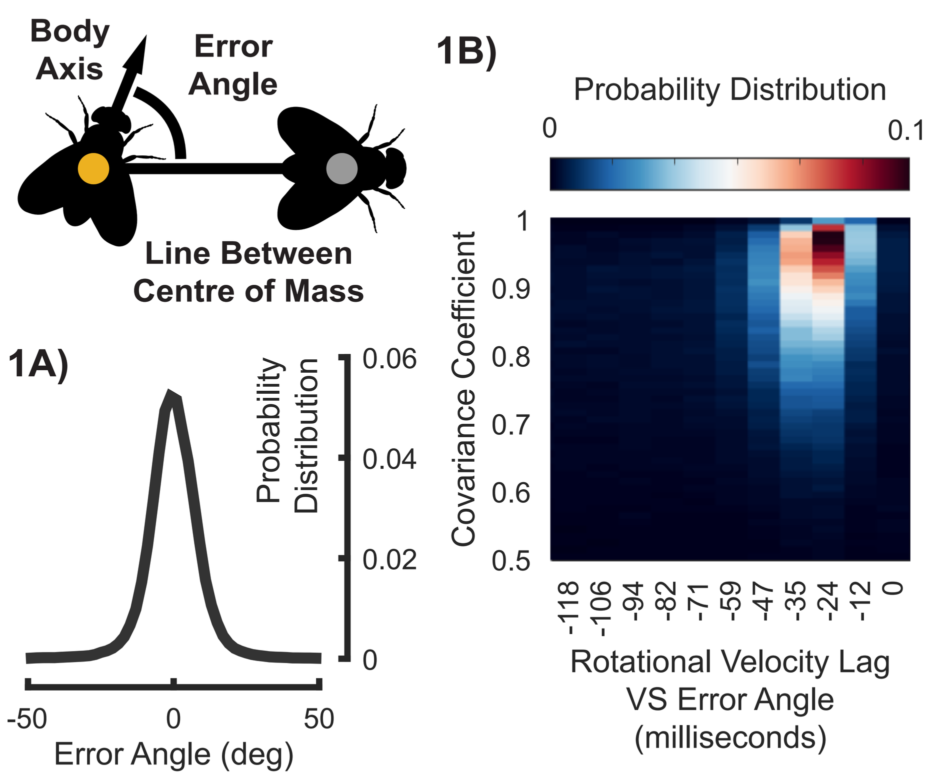
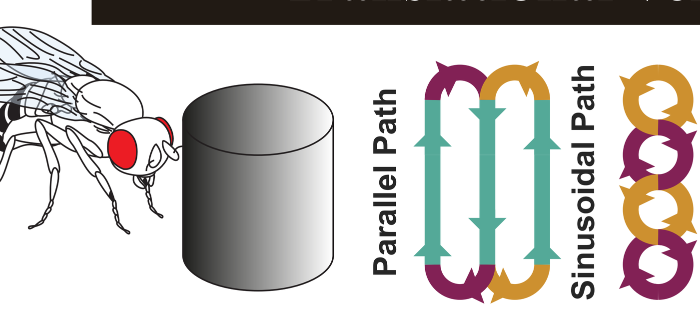


Figure 1: A) As the male fly chases the female, he faces the female position (error angle probability distribution is kept around 0 degrees). Traditionally, the male has been described to use rotational velocity to move his body axis towards the female position (T. Sten et al, 2021; R. Cook, 1979). **B)** The cross-covariance between the rotational velocity of the male and the error angle, calculated for a window 250ms around each frame where the male chased the female. From the cross-covariance result for each frame, the highest correlation coefficient and corresponding delay were extracted. The result shows that the variance in error angle is accounted for by the male's rotational velocity with a lag of ~24ms.

Translational Velocity is Prominent in Magnet Chasing



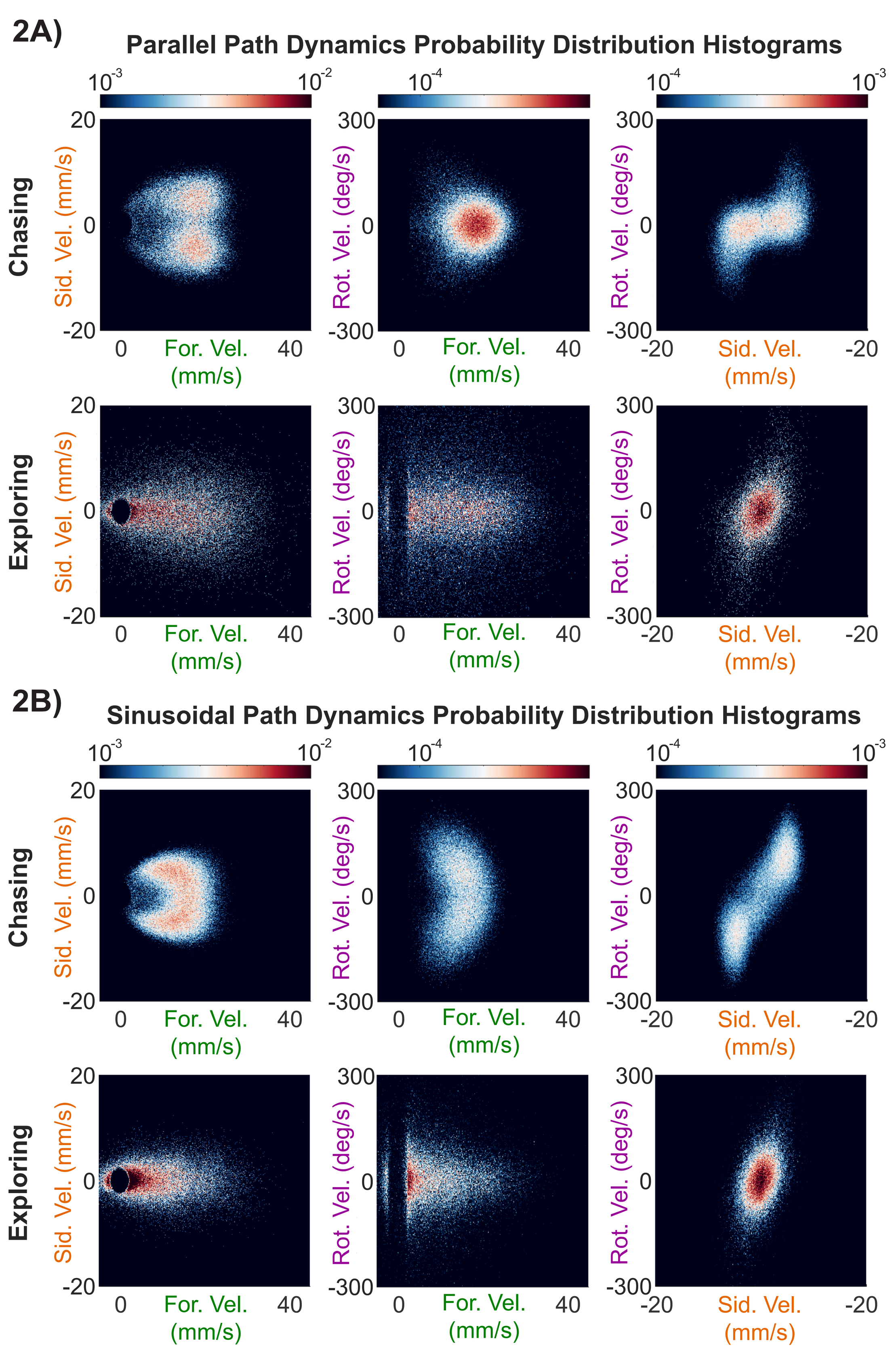
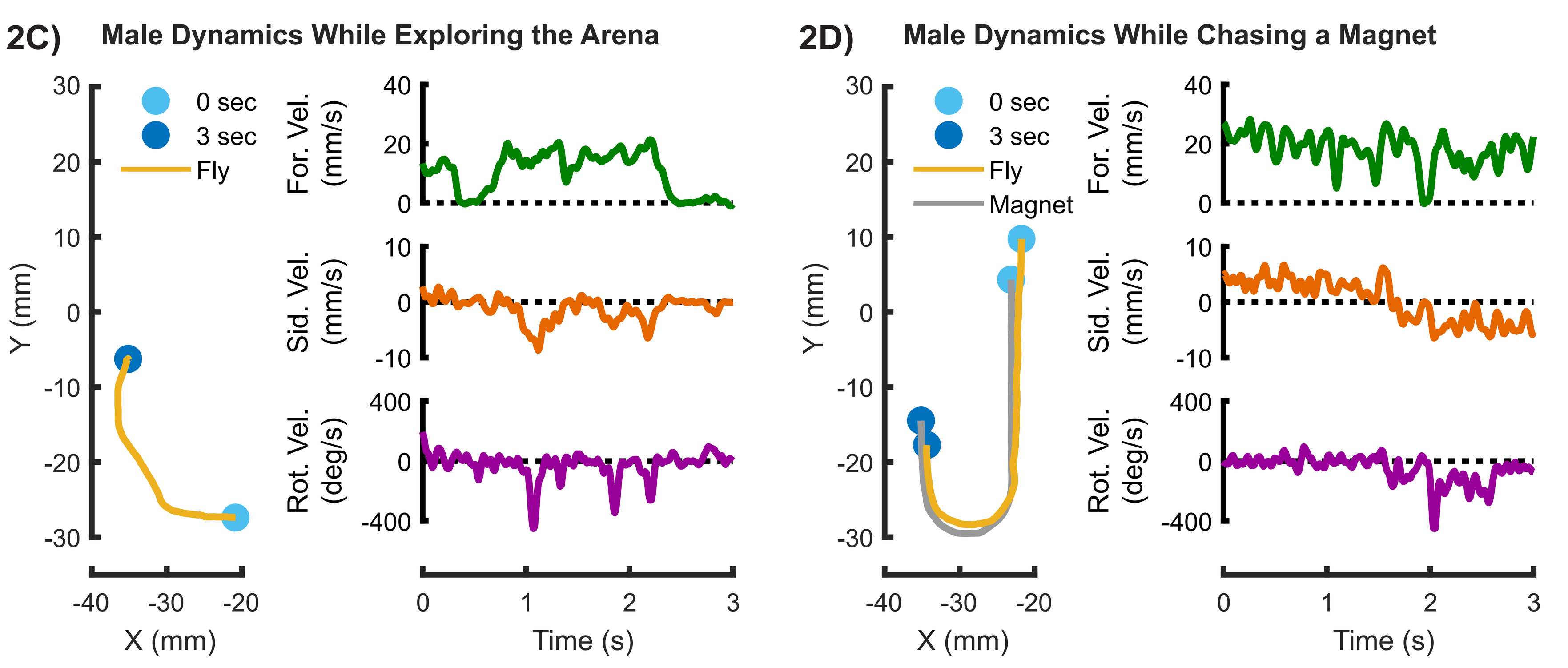
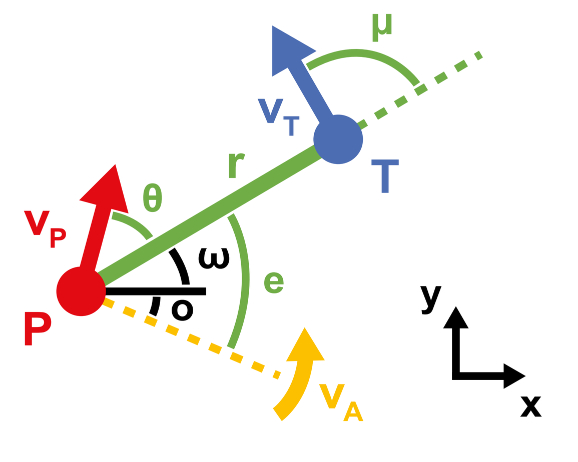


Figure 2: A) & B) Joint distributions of body velocity components: forward, sideways, and rotational, during the male fly chasing and exploratory behaviour, while a magnet moves along a parallel and a sinusoidal paths represented above, respectively. The male engages in the chasing of the magnet due to the continuous artificial activation of P1 neurons (Y. Pan et al, 2012). A strong prominence of high translational body velocity components (sideways and forward) is observed during chasing behaviour. It has been reported that sideways and rotational velocities are highly coupled (B. DeAngelis et al., 2019). This coupling can be observed during the male's exploratory behaviour regardless of the magnet path. During chasing behaviour, the coupling seems to be broken, especially when the magnet follows the parallel path. **C) & D)** Male fly (and magnet for **D)**) paths and time series of body velocity components of the male for those paths, during exploratory and chasing behaviour, respectively.



Translational Velocity Shows Anticipatory Capability and it can Reduce Rotational Delay



$$\dot{e} = v_A + \frac{v_P \sin(\theta)}{r} - \frac{v_T \sin(\mu)}{r}$$

$$\dot{r} = v_T\cos(\mu) - v_P\cos(\theta)$$

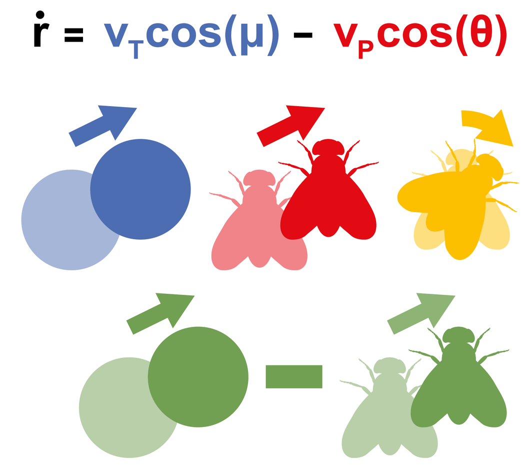
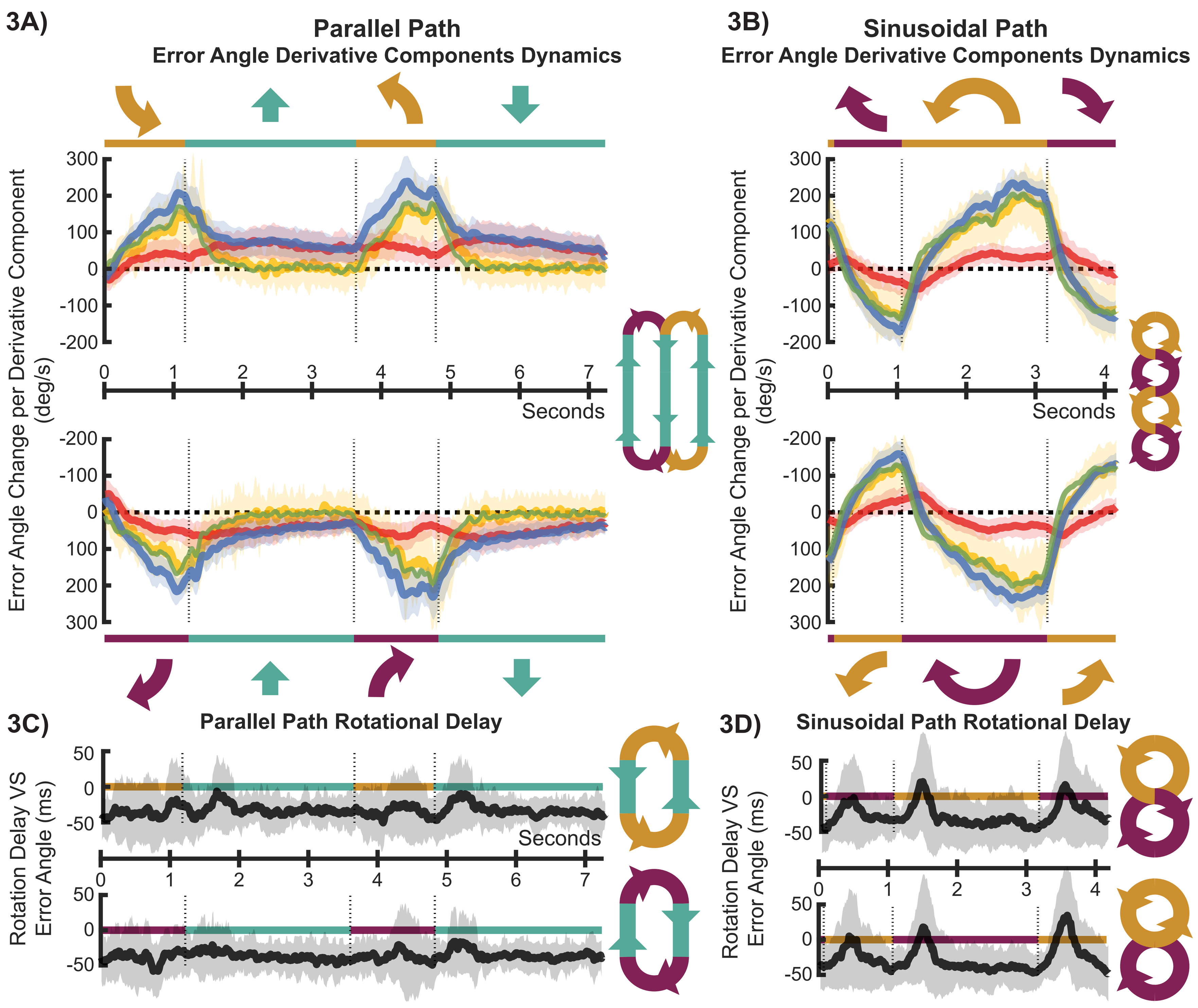
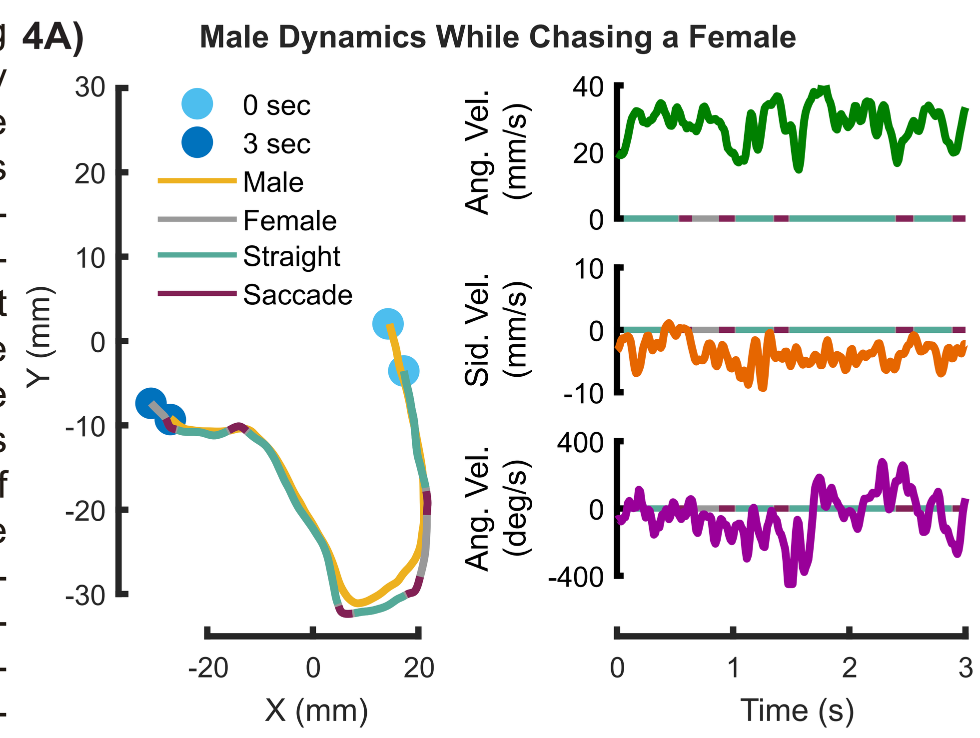


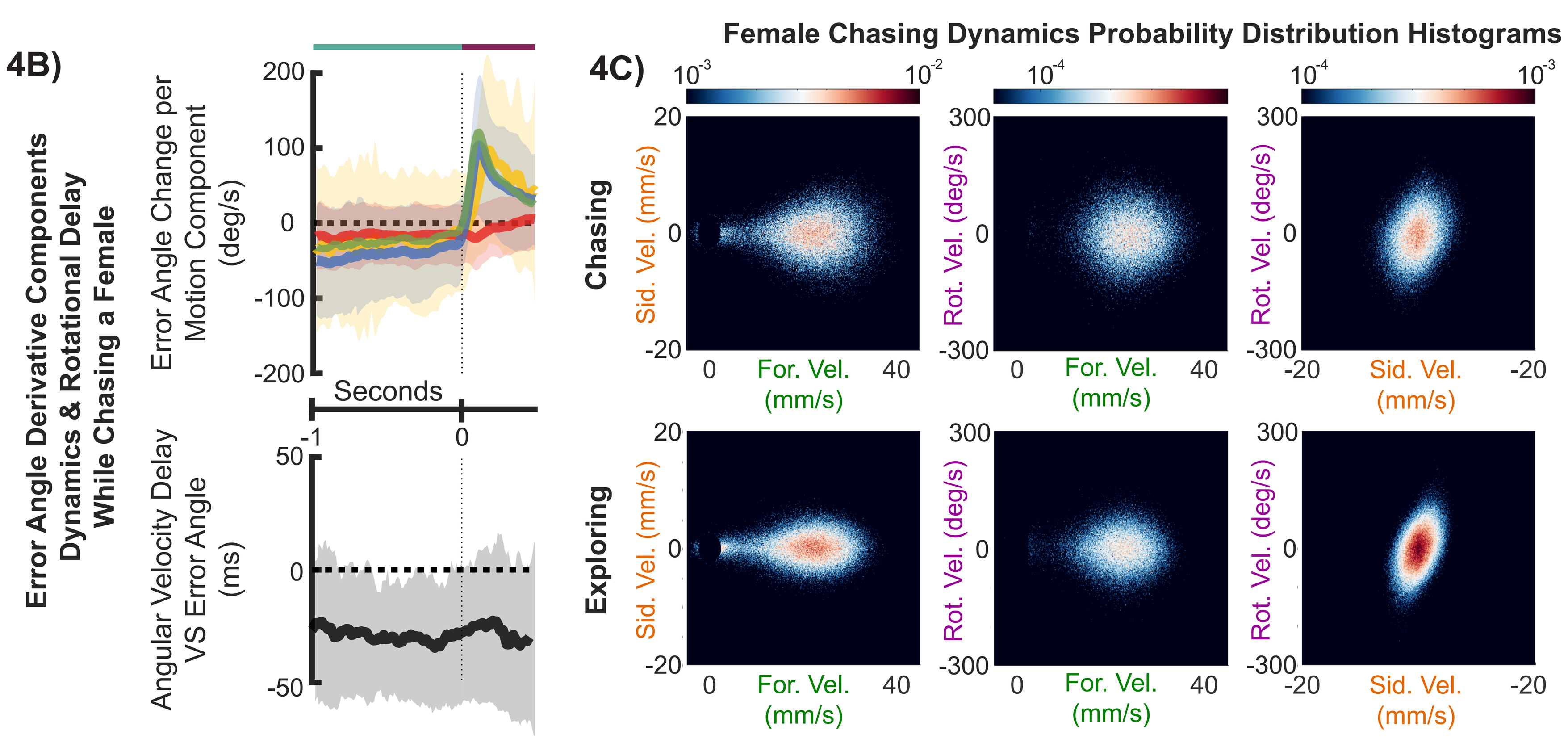
Figure 3: A) & B) The magnet follows a parallel or a sinusoidal path respectively (schematic on the right of the respective figure). The figures show how the different derivative components of the error angle change along the magnet path when the male chases the magnet. The derivative components are given by the equations on the left and are magnet motion, male translation, male rotation, and the magnet motion change not accounted by male translation. The male translation can completely compensate the magnet motion during the parallel path straight segments, implying that the male is moving alongside the magnet in real time. The amount of magnet motion not accounted for by male translation is corrected by the male rotation with a delay, keeping the error angle constant and minimized (**Figure 1A**). **C) & D)** Using the same calculations as in **Figure 1B**), the lag between the rotational velocity and the error angle is plotted along the magnet path, as the male chases the magnet. When the change in error angle induced by the magnet motion changes signal (**Figure 3A & 3B**), it can be observed that the delay between rotation and error angle is reduced or eliminated (**Figure 3D**). It is also noteworthy that these moments match the increase by the male translation (most evident in **Figure 3B**). Overall, the results show an important contribution of male translation on changing the error angle during chasing and suggest anticipatory capability behind this translation.



Translational Velocity During Female Chasing

Figure 4: A) Male and female paths during chasing and time series of the male's body velocity components. The path of the female is divided into straight and saccadic sections (T. Cruz et al, 2021). Prominent sideways velocity uncoupled from rotational velocity is observed. **B)** Same as **Figure 3A) & 3C)** but plotted when the male is chasing a female that, after a straight segment, saccades to the opposite side fromt where the male stands relative to the female. C) Joint distributions of body velocity components during female chasing and exploratory behaviour. The similarities between chasing and exploratory behaviours can be due to the target (female) following a path constrained by the usual sideways and rotational velocities coupling.





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