```
In [1]: import pandas as pd
        import numpy as np
        import matplotlib.pyplot as plt
        from scipy.stats import norm
        import plots # Custom functions for plotting
```

Tricking your cerebellum

Exercise 4 – Motor Noise (Group A)

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*equal contribution

Task 1: Implementation of motor noise

Implement motor noise as additional perturbation

We define these global variables to control the noise strength throughout the blocks and each invididual trial:

```
{python}
noise_mean = 0
noise_std = 0
noise_active = False
noise_instance = 0
```

The noise is sampled from a random distribution:

```
{python}
def sample_random_noise():
    global noise_mean, noise_std
    return np.random.normal(noise_mean, noise_std)
```

Noise is applied as soon as the pint leaves the control zone:

```
{python}
def apply_noise():
    global pint_velocity, noise_instance
    pint_velocity[0] += noise_instance

# PINT_MOVEMENTS
def handle_mouse_input():
    ...
    else:
        ...
        apply_noise()
       ...
    ...
```

Display the text 'Drinking beer' and light up the yellow in the beer pint after the motor noise has been increased

We display the text and change the color of the beer when setting up the block. Noise parameters are set when defining the blocks:

```
{python}
...

friction_decrease = 0.003
BASE_FRICTION = 0.99 - (3 * friction_decrease)

...

def setup_block(block_number):
    ...

    drink_beer = block.get("drink_beer", False)
    if drink_beer:
        display_message("Drinking beer!", length = 2000)
        beer_alpha -= beer_alpha_decrease
        if friction + friction_decrease < 1:
            friction += friction_decrease

    noise_active = block.get("noise_active", False)
    noise_mean = block.get("noise_mean", 0)
    noise_std = block.get("noise_std", 0)

    # Generate new perturbation noise
    if noise_active:
        noise_instance = sample_random_noise()
    else:
        noise_instance = 0

    ...
```

Design your own experiment to test effect of motor noise

```
{python}
small_noise_mean = 0
small_noise_std = 1

medium_noise_mean = 1.5
medium_noise_std = 2

large_noise_mean = 2.5
large_noise_std = 3

sudden_force = 2
n_trials_no_perturbation = 10
n_trials_perturbation = 30
feedback_setting = "endpos"

block_structure = [
    # 1
    {
        "feedback": feedback_setting, "num_trials": n_trials_no_perturbation,
        "perturbation": False,
        "drink_beer": False,
        "noise_active": False,
    },
    {
        "feedback": feedback_setting, "num_trials": n_trials_perturbation,
        "perturbation": True, "gradual": False, "sudden_force": sudden_force,
        "drink_beer": False,
        "noise_active": False
    },
    {
        "feedback": feedback_setting, "num_trials": n_trials_no_perturbation,
        "perturbation": False,
        "drink_beer": False,
        "noise_active": False
    },

    # 2
    {
        "feedback": feedback_setting, "num_trials": n_trials_no_perturbation,
        "perturbation": False,
        "drink_beer": True,
        "noise_active": True, "noise_mean": small_noise_mean, "noise_std":
small_noise_std
    },
    {
        "feedback": feedback_setting, "num_trials": n_trials_perturbation,
        "perturbation": True, "gradual": False, "sudden_force": sudden_force,
        "drink_beer": False,
        "noise_active": True, "noise_mean": small_noise_mean, "noise_std":
small_noise_std
    },
    {
        "feedback": feedback_setting, "num_trials": n_trials_no_perturbation,
        "perturbation": False,
        "drink_beer": False,
        "noise_active": True, "noise_mean": small_noise_mean, "noise_std":
small_noise_std
    },

    # 3
    {
        "feedback": feedback_setting, "num_trials": n_trials_no_perturbation,
        "perturbation": False,
        "drink_beer": True,
        "noise_active": True, "noise_mean": medium_noise_mean, "noise_std":
medium_noise_std
    },
    {
        "feedback": feedback_setting, "num_trials": n_trials_perturbation,
        "perturbation": True, "gradual": False, "sudden_force": sudden_force,
        "drink_beer": False,
        "noise_active": True, "noise_mean": medium_noise_mean, "noise_std":
medium_noise_std
    },
    {
        "feedback": feedback_setting, "num_trials": n_trials_no_perturbation,
        "perturbation": False,
        "drink_beer": False,
        "noise_active": True, "noise_mean": medium_noise_mean, "noise_std":
medium_noise_std
    },

    # 4
    {
        "feedback": feedback_setting, "num_trials": n_trials_no_perturbation,
        "perturbation": False,
        "drink_beer": True,
        "noise_active": True, "noise_mean": large_noise_mean, "noise_std":
large_noise_std
    },
    {
        "feedback": feedback_setting, "num_trials": n_trials_perturbation,
        "perturbation": True, "gradual": False, "sudden_force": sudden_force,
        "drink_beer": False,
        "noise_active": True, "noise_mean": large_noise_mean, "noise_std":
large_noise_std
    },
    {
        "feedback": feedback_setting, "num_trials": n_trials_no_perturbation,
        "perturbation": False,
        "drink_beer": False,
        "noise_active": True, "noise_mean": large_noise_mean, "noise_std":
large_noise_std
    }
]
```

Task 2: Analysis of motor noise on unbiased subjects

By the end of the trials, the unbiased subject got a bit annoyed with the task and tended to perform shorter throws in order to get the experiment over with quicker.

```
In [2]: # Read subject data
        experiment, full_experiment = plots.define_experiment()

        subject1 = pd.read_csv("Subject_1.csv")
        subject1 = pd.merge(subject1, full_experiment, on = "Trial")
```

```
In [3]: small_noise_mean = 0
        small_noise_std = 1

        medium_noise_mean = 1.5
        medium_noise_std = 2

        large_noise_mean = 2.5
        large_noise_std = 3

        x = np.linspace(-10, 12, 1000)
        y_small = norm.pdf(x, small_noise_mean, small_noise_std)
        y_medium = norm.pdf(x, medium_noise_mean, medium_noise_std)
        y_large = norm.pdf(x, large_noise_mean, large_noise_std)
```

```
In [4]: fig, axs = plt.subplots(nrows = 1, ncols = 2, figsize = (12, 4))

        axs[0].plot(x, y_small, label = rf"Small noise: $\mu = {small_noise_mean}, \sigma = {small_noise_st
        axs[0].plot(x, y_medium, label = rf"Medium noise: $\mu = {medium_noise_mean}, \sigma = {medium_nois
        axs[0].plot(x, y_large, label = rf"Large noise: $\mu = {large_noise_mean}, \sigma = {large_noise_st
        axs[0].set_xlabel("Motor noise °")
        axs[0].set_ylabel("Probability density")
        axs[0].set_title("Distribution of small, medium, and large motor noise")
        axs[0].legend(loc = "center left", bbox_to_anchor = (1, 0.5))

        colors, unique_periods = plots.get_experiment_colors(experiment)

        # Show the different experimental periods
        for i, change in experiment.iterrows():
            label = change.Type if change.Type in unique_periods else ""
            unique_periods = unique_periods[unique_periods != change.Type]

            start = change.Trial
            end = change.TrialEnd

            axs[1].axvspan(
                start, end,
                alpha = 0.2,
                label = label,
                color = colors.get(change.Type)
            )

        axs[1].scatter(
            subject1.Trial,
            subject1.NoiseInstance,
            s = 5,
            label = "Noise"
        )
        axs[1].legend(loc = "center left", bbox_to_anchor = (1, 0.5))
        axs[1].set_title("Noise in each attempt")
        axs[1].set_xlabel("Motor noise °")
        axs[1].set_ylabel("Attempt")

        fig.tight_layout()
        plt.show()
```

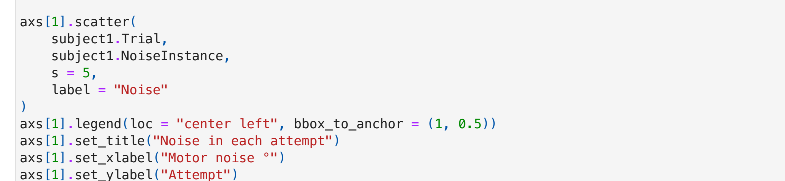


Figure 1. (Left) Distributions of the motor noise used throughout the experiment. (Right) Individual noise instances during each attempt.

```
In [5]: fig, axs = plt.subplots(nrows = 1, ncols = 2, figsize = (12, 4))
        plots.plot_running_score(experiment, subjects = [subject1], ax = axs[0], show_legend = False)
        plots.plot_trial_score(experiment, subjects = [subject1], ax = axs[1])
        fig.tight_layout()
```

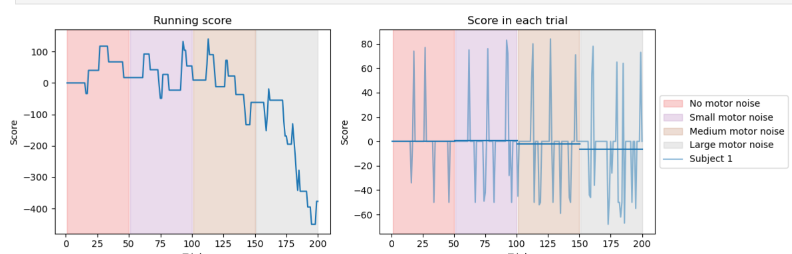


Figure 2. (Left) The running score across the experiment and (right) the score for each trial, with vertical lines representing the mean score for each block, for subject 1. The different experimental blocks are visually highlighted. The subject shows a significant decline in performance during the final block.

```
In [6]: plots.plot_throw_positions(subject1)
```

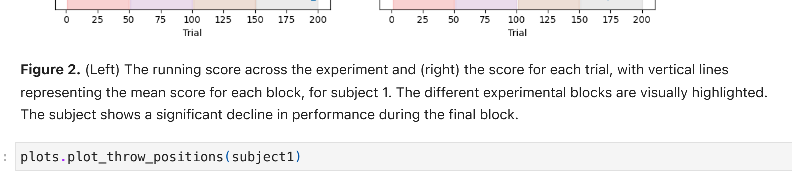


Figure 3.1. Final pint positions for subject 1. (Right) The mean final position, marked by a cross, and its error, marked by the confidence ellipse. (Left) Final pint position for all trials. The experimental blocks are marked by different colors. The variability of the final position tends to increase with increasing motor noise.

```
In [7]: plots.plot_throw_perturbation(subject1)
```

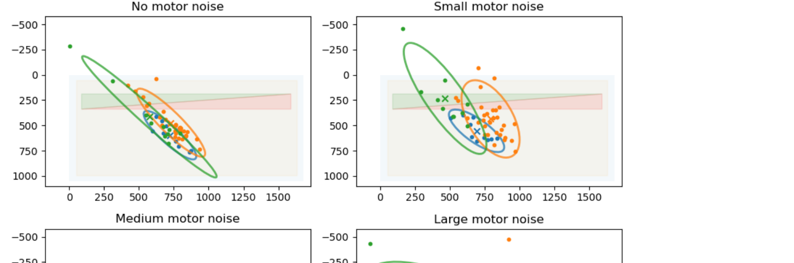


Figure 3.2. Final pint positions, their mean and confidence ellipse during no perturbation and perturbation periods of each experimental block for subject 1. For all blocks, perturbed attempts are shifted in the direction of perturbation. For small motor noise and large motor noise there is a visible after-effect, and the mean of the final position is shifted in the direction opposite to perturbation.

Task 3: Discussion

Is feedback still helpful even if motor noise is present? How large can the motor noise be until learning no longer takes place?

We notice that the subject's performance declines with increasing motor noise, and their attempts appear more random. It is difficult to attribute this to the induced noise alone; during the experiment, the subject was getting increasingly annoyed when they could not control the pint, and started performing random throws out of frustration by the end of the experiment.

However, in the case of the small motor noise, the subject has clearly learned to adapt to the induced perturbation. This is visible in the after effect - the unperturbed trials after the perturbation are shifted in the opposite direction to the perturbation, stronger than before the perturbation was induced. For the medium motor noise, the effect is not as pronounced. In the case of the large motor noise, no comment can be made - it is unclear whether the subject learned something or the observed after-effect appears by chance.

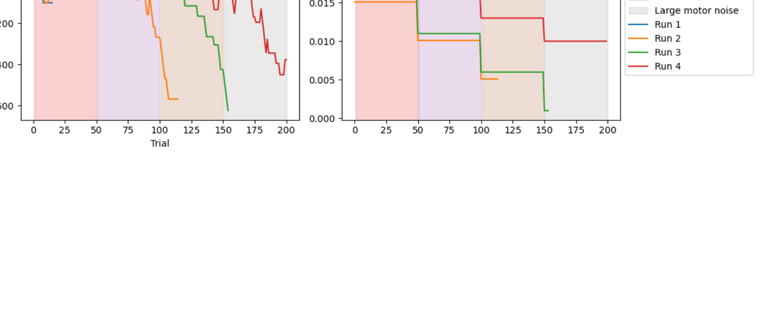
Overall, the feedback is helpful when the noise is not too strong and the subject can still link their actions to the results they produce (and thus successfully update the internal model). Even though this process is supposed to be subconscious, the large noise was quite strong and the subject noticed that the system does not behave as they expect, thus getting frustrated and performing poorly. So, the second question is more difficult to answer with this specific experiment (or at least the data we have).

Task 4

Defining correct experimental settings as well as being consistent is as important as the experiment itself. Due to this we noticed a couple of things:

- First being consistent with respect to the experimental material is quite important. In the classroom we set the friction parameters such that it was challenging to hit the green wedge but also not impossible to run over. Those settings where determined on a MacBook. On the other hand while performing the experiments on another computer (ThinkPad), we noticed it was now way harder to reach the target. We suppose both laptops had different settings with respect to the maximal cursor speed. Therefore, we started multiple runs with the subjects to find nice friction parameters on the ThinkPad. This leads us directly to the next point.
- Frustration is a very important thing if you would like to have the subject motivation to perform the task as good as possible. Therefore, it was challenging to keep the subject motivated while finding new friction parameters (Run 1 - 3). The subject aborted the runs multiple times, either because it could not reach the target (Run 1) or just overshoots almost all the time (run 2 - 3) and needed persuasion (real beer afterwards) to start the final run (run 4). The next source of frustration came along when we started to perturb the experiment. The subject became not willing to learn anything but just rather complete the task. So we conclude: wisely chosen parameters also in perturbation (maybe truncate perturbation next time) are crucial.

```
In [8]: subject2 = pd.read_csv("logs_1.csv")
        subject2 = pd.merge(subject2, full_experiment, on = "Trial")
        subject3 = pd.read_csv("logs_2.csv")
        subject3 = pd.merge(subject3, full_experiment, on = "Trial")
        subject4 = pd.read_csv("logs_3.csv")
        subject4 = pd.merge(subject4, full_experiment, on = "Trial")
        fig, axs = plt.subplots(nrows = 1, ncols = 2, figsize = (12, 4), sharex=True)
        plots.plot_running_score(experiment, subjects = [subject2, subject3, subject4, subject1,], ax = axs
        plots.plot_experiment_layout(experiment, ax=axs[1])
        plt.plot(1- subject2["Friction"], label="Run 1")
        plt.plot(1- subject3["Friction"], label="Run 2")
        plt.plot(1- subject4["Friction"], label="Run 3")
        plt.plot(1- subject1["Friction"], label="Run 4")
        axs[1].set_title("Friction Coefficient")
        axs[1].legend(loc = "center left", bbox_to_anchor = (1, 0.5))
        # plots.plot_trial_score(experiment, subjects = [subject1], ax = axs[1])
        fig.tight_layout()
```


Running score
Score
Trial
Friction Coefficient
No motor noise
Small motor noise
Medium motor noise
Large motor noise
Run 1
Run 2
Run 3
Run 4