**Loom History and Current Goals:**

To date, we have created and collected data for two versions of Loom (Loom v1 and Loom v2). There is a published conference paper and a journal article in review for data collected from Loom v1, and now we must decide what we are going to do with the data from Loom v2. Currently, the goal is to publish findings from the Loom v2 dataset, an autism journal. To do this, we must make a leap from the first paper’s finding and say something relevant to the field. The purpose of this document is to find a **potential** avenue of questioning that will drive the analysis and creation of this future publication.

From Loom v1, we were able to characterize how a virtual presence affects individual measures of gaze, movement, and arousal in autism. While interesting, due to the novel methodology, the characterization of difference alone does not really answer any questions about how social interaction is differently formulated and performed in autism, which is really the goal of using a dynamic social interaction game like Loom. We asserted that there are certain instances in movement, gaze behavior, and arousal where timing and degree of autonomic response are different in autistics compared to non-autistics and that most of these instances occur in a social cooperative scenario. It is encouraging that most of the individual findings for movement, gaze, and arousal have been produced before in some regard during smaller uni-measure experiments because most of those studies were not done in VR, so this work potentially adds credence to the paradigm as a viable substitute for some avenues of research. The gaze duration data for the view wall is particularly interesting because it shows a known *skill* that autistics have for static search and detail detection in the context of a highly dynamic situation. *(Baron-Cohen, 2017 - Editorial Perspective: Neurodiversity – a revolutionary concept for autism and psychiatry)*. From our current analysis, this was the only example of autistics being better than non-autistics as the other data for gaze and movement was found to be either statistically similar or autistic people were slower compared to controls. I would like to use the data set from Loom v2 to say something more specific and relevant to the topic of social interaction. Unfortunately, articulating how these autistic characterizations explain anything about their troubles with social interaction is difficult. Some of the reasons for this include direct challenges to our findings like:

1. This is a virtual environment and may not fully mimic a real social interaction.
2. The differences found between the groups are caused by something indirectly associated with social interaction, such as visual or game complexity, cognitive load ect…. *This covariate would have to be present only in the cooperative condition since that is where we see the majority of group differences.*

And more conceptual challenges regarding the nature of social interaction. Simply, it is difficult to describe specifically why autistic individuals are incapable of fluid social interaction when we do not really have a baseline for what comprehensive social interaction is.

**Finding a research question that incorporates multiple characteristics of autism and social interaction**:

Some autistic characteristics are easier to connect to their issues with social interaction than others, such as the use of gaze when making (or not making) eye contact or the lack of accuracy when identifying human emotions and social cues. Even so, these examples are difficult to contextualize more broadly about social interaction because of the aforementioned lack of specificity on the topic. It is plausible that these predominantly visual and cognitive characteristics of autism could be related to other autism-specific characteristics like their issues with motor control.

Combining these domains is an important step for the autism field because of the high likelihood that there is an underlying reason for both occurrences or at least some kind of a link. This reason, whatever it is, could be a vital piece of information for understanding the challenges that autistic people have with social interaction and developing practical clinical applications. Currently, Loom cannot do mechanistic research that would require neuroimaging techniques like EEG or fNIRS (possibly a future addition to the system), which would provide more tangible evidence for a connection to the domains of gaze movement and arousal, but it may not be necessary at this stage. Using Loom, we can investigate how autistic individuals are functionally producing gaze, movement and arousal responses in a social and non-social context. Our findings could be used as justification for future research attempting to find mechanistic relationships for these domains. Therefore, I believe that my task must now be to find a measure that answers the questions:

**Q1:** How do autistic individuals combine the use of gaze & movement (and possibly arousal) differently than non-autistic people?

**Q2:** Do social situations/contexts impact this combined use of gaze & movement?

**A Measure Combining Movement, Gaze, and Arousal:**

To understand how individuals with autism are functionally combining multiple domains of action differently than non-autistics, we must find a task and measure that incorporates each of these domains.

Rather than having a standard start and stop to a task/trial, Loom allows the player to retain more agency over their decisions on how best to achieve a goal. In the pursuit of this goal, Loom facilitates several movements that players are required to do to complete the game’s objective. It is more useful to say that Loom allows players the freedom to choose the order of their actions, but the individual actions themselves are relatively consistent across players. There may be a question in the future about how the sequencing of actions changes between groups. The incorporation of tasks that are both positively and negatively affected by autism could be interesting to explore. The cross participant **intra-game tasks** that Loom currently facilitates are:

* Grabbing a cube on the Play Wall
* Placing a cube into a Drop Zone
* Checking the View Wall for information
* Turning from the Play Wall to the Build Wall

If we want to use some or all of these intra-game tasks as the structure for measurement, we must establish a precise timeline describing when each of them starts and stops. The peaks and valleys shown in the figure below could be a good place to start determining these breakpoints.



Additionally, we must at least consider previous research that has been done and incorporate it into the measure we are creating. This way, we can reference and expand upon previously established results. A good place to start is the *reach-to-grasp* literature, which is a highly researched movement in autism (and elsewhere) and is a developmental milestone for movement, so there is a direct link to clinical applications (which is good).

This paper: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1693116/pdf/12639336.pdf>

Is a foundational report on the topic of reach-to-grasp in autism. It outlines the kinematic differences of autism as well as a more complex topic, which is the differences in motor planning found in autistic individuals. The kinematic differences that lead to slower movement times are something that Loom 1 was able to show. Although reach-to-grasp can be described as two different movements, functionally, they are happening in parallel. While a person is reaching for an object, they are also preparing the aperture of their hand’s fingers to grasp it upon arrival. This parallel movement, which brings in a new term, “motor planning,” is now a full avenue of research in autism due to the differences shown here and in other places.

Motor Planning Paper: <https://www.sciencedirect.com/science/article/pii/S175094671>

Movement and gaze occurring in parallel for a singular goal could be a good place to start with the Loom v2 analysis.

This study: <https://onlinelibrary.wiley.com/doi/epdf/10.1002/aur.2478?saml_referrer>

Outlines a potential question about how autistic people are using their gaze and head movement in coordination differently than non-autistic people. Loom can expand upon this research by also including goal-oriented hand movements, which would be new to the field.

Using this potential measure, it is possible that we could answer Q1, but it doesn’t really fully address anything about social interaction and **Q2**. To do this, we need to have a better understanding of how social interaction and motor control are related. Motor abnormalities in autism (Fournier,Hass,Naik,Lodha,&Cauraugh,2010) have been found in many instances. However, there is a large amount of variability in these findings, and it is unclear as to why. Obstructed development or interventions could be the cause. Differences in neural physiology have also been consistently observed in autism, specifically in cerebral hemispheres, caudate nucleus, and cerebellum. Additionally, less integration among brain regions has also been found in autism. Decreased connectivity across the motor execution network relative to children with normal neurodevelopment could be one reason for the difference we see in motor control. These motor abnormalities still do not really get us that much closer to the issues found with social interaction. So, a more conceptual approach is needed.

**Literature concerning the combination of Movement and Social Interaction:**

# This paper: So close yet so far: Motor anomalies impacting on social functioning in autism spectrum disorder – Casatelli et al

<https://www.sciencedirect.com/science/article/pii/S014976341530258X?casa_token=cuEVAP19BoUAAAAA:nNyS5Ksjwd_sqVBNF6Bg2wBDDzkz6IUJ0JqqNn_F_n92wfyX38tffzihl_g-cKCcDD7v_LMM#bib0095>

In this paper, the authors describe terms that could roughly outline a conceptual foundation for the different kinds of connections that exist between social interaction and movement. These terms **are “motor resonance” and “motor interference.”**

**-Quote:** “Referring to ASD, the first one (motor resonance) can impact the ability to directly understand (i.e., motor-based understanding) others’ behavior, whereas the second (motor interference) one may be considered a more general and pervasive motor marker of social anomalies.”

**Motor Resonance:** The kinds of subjects that are discussed in the paper involving motor resonance are focused on the autistic differences in motor planning and visual observation of movement. For example ([Cattaneo et al., 2007](https://www.sciencedirect.com/science/article/pii/S014976341530258X?casa_token=cuEVAP19BoUAAAAA:nNyS5Ksjwd_sqVBNF6Bg2wBDDzkz6IUJ0JqqNn_F_n92wfyX38tffzihl_g-cKCcDD7v_LMM#bib0115)) is a really cool experiment that uses EMG attached to the mouth muscle to record activation on a task that asks autistic and non-autistic kids to perform two actions. Action 1) Picking up food and putting it in the mouth and Action 2) Picking up food and putting it into a bin. The autistic group showed a late mouth activation occurring after the grabbing portion of the action in contrast to the non-autistic group, which did not. This implies that there is some kind of neurological issue affecting the functional activation of parallel movement and the motor planning of future movement. Interestingly, this study also contained a second “observational” condition where the participants watched someone else do both actions. The non-autistic group showed similar mouth activation while watching some perform the eating action, but the autistic group showed no activation while observing either action. Both of these results imply that the autistic group has difficulty visually encoding the goal of an action, which is more pronounced in a purely observational situations. The Casatelli paper also cites another paper:  [Boria et al., 2009](https://www.sciencedirect.com/science/article/pii/S014976341530258X?casa_token=cuEVAP19BoUAAAAA:nNyS5Ksjwd_sqVBNF6Bg2wBDDzkz6IUJ0JqqNn_F_n92wfyX38tffzihl_g-cKCcDD7v_LMM#bib0050) , which further highlights this inability to infer intention from motor cues specifically.

Regarding the functional use of parallel and future movements, I think there is something that we can learn about motor resonance using the head, hand, gaze combination measure (need a better/shorter name for this). **For the autistic group, I hypothesize that we will find some scenarios where the head/hands will be lagging significantly behind the non-autistic group**. This is, I think, most likely going to happen for the placement of cubes due to the increased complexity of the movement. More of a motor planning load is possibly more likely to show up in our data. Regarding the activation of movements when observing the partner, this is potentially more challenging due to the overall low frequency of gaze time spent on the partner, as well as the lack of human characteristics of movement.

I am not quite sure how the impact of the social context will affect this result. There is not much of a partner to look at visually, and the preliminary data shows nobody is really looking anyway. Therefore, if there is a difference in outcome between the contexts, then it is possible that we need to dive deeper into possible explanations for this.

* Visual complexity
* Game complexity
* Type of in-game movement will most likely be important

Alternatively, there might be something else specifically to do with the social context. Unlike most of the research that I have looked at here, Loom is a highly dynamic situation. It is possible that the reality of the social situation is affecting the participants in a way that we can not detect by measuring gaze and movement but affects them both in a downstream manner. (FIGURE OUT WHAT DOWNSTREAM MEANS)

**Motor Interference:**

Motor interference in autism is potentially a more direct link to the physical differences found in this population and something that we can access using the data we get from Loom. Motor interference is linked to the domains gaze and the perception of movement, imitation, prediction and biological vs non-biological movement, and mirror neurons (probably). These are all domains that have been researched and found to be irregular or related in some way to people with autism.

The primary phenomenon that is discussed here is what is called an “interference effect.” This effect is how the observation from a human can disrupt or interfere with the production of that movement in either congruent or incongruent contexts. For example, moving the arm up and down or right to left, back and forth in a sinusoidal pattern.

**Kilner et al. (2003) & (2007)**

In this study, they clearly outline how the observation of an incongruent movement negatively affects the production of movement ONLY when observing human movement compared to observing robot movement. It suggests that we must try to understand how human movement is different from a robot’s in order to understand why this disruption in movement occurs in the context of biological movement observation. To define the difference between biological and non-biological movement, some of the literature uses a minimum-jerk velocity profile as a divider for biological and non-biological movement. For example, movement that varies in speed vs. continuous movement (Flash & Hogan, 1985).

**(Cook et al., 2014)**

In this study, they examine the movement interference effect from Kilner et al. (2003) in an autistic population. They show an effect of the autistic population having no interference effect when observing human or robot movements. The non-ASD controls did show an interference effect when looking at the humans.

“This result is in line with the finding of Pierno et al. (2008) that visuomotor priming was greater for control children relative to children with ASC following observation of human actions. However that visual motor priming was greater for ASD children when looking at a robot.”

Regardless of whether or not the autistic group responded to the robot condition as anticipated, it is nt from this study that autistic individuals are not processing and replicating human movements in quite the same way as non-autistic people. While this knowledge is valuable it is still very far away from reality. How often do people just mimic another person’s movement? Actually, maybe a lot, I am not sure, but they definitely do not just do the same movement over and over repeatedly.

**A Gap in the Literature: Movement and Social Interaction -> Autism Intervention**

From what I can tell, (Casatelli et al., 2016) is kind of where the lit erature ends (maybe that explains the title of the paper) for movement and its connections to social interaction. There is a body of literature that is new which is looking at using movement and exercise as intervention tools for autism and issues with social interaction. The preliminary studies have indicated very promising positive results (Reinders et al., 2019). However, there is a gap that connects the issues that we see in autism directly to these interventions. It is difficult to design interventions based around research that is done in such a controlled and formalized manner as I discussed above. How can you design an intervention or suggest what types of stimuli or movements to include if the research is only observing simple sinusoidal arm movements that are measured at specific moments in time? This is potentially too far away from the reality of how movement is used in social interaction.

How can we use Loom, which is a more dynamically real social scenario, and extract some usable information about movement and its impacts on social interaction? In the conceptual contexts of motor resonance and motor interference, I think that there are a couple of avenues worth exploring:

1. The main one is the eye, head, and hand measure compared strictly across conditions
2. I would also like to know how this measure changes depending on the contexts of the Walls. For instance, the performance on the Play Wall and the View Wall, which we can claim are tasks that are negatively or positively affected by autism.
3. There is definitely going to be a difference in head movement for the Play Wall vs. the Build and View Wall because I expect that the Play Wall will not require head movements do the limited degrees of change in gaze when finding a cube.

I am not quite sure for to incorporate the concept of perception of movement into this study. I think we can assume that it is happening to some degree. However, that degree might be low, or we may not be fully recording it due to the limitations of the distance and resolution of the partner. **At the very least, I think we must assume that the movements that are being observed are coming from a “robot” body but with biological movement.** This is an important point in the context of the research that has been done.

Next steps:

1. Find out which movements are affected by social context so we can connect this to the intervention literature
2. Figure out how arousal fits into this.
3. Design the Next Study to “find the consistencies within the complexities”

**(**Pineda et al., 2014):ASD neurofeedback training

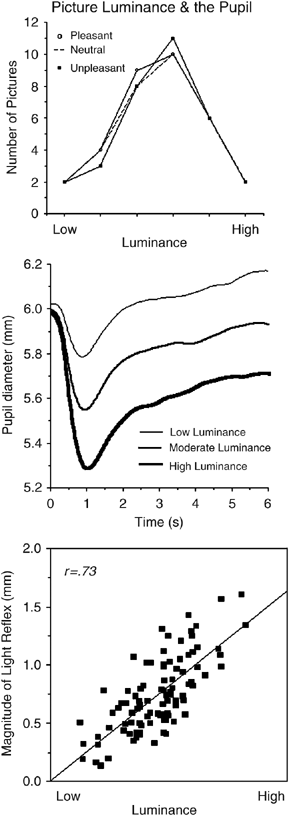
**Arousal – General:**

Arousal is a very scattered domain of research. Among the disjointed branches, it claims to be of extreme importance for cognition, health assessment, and task performance. The odd part is that most of the research fails to articulate a clear connection between the real time changes in arousal and these domains. The earliest literature was focused on understanding how arousal could be measured in response to hedonically salient stimuli.

A seminal paper in pupillometry (Hess & Polt, 1960) gives some initial evidence for the effects of emotional faces on arousal and pupil size. Although famous, these results are not very replicable, and there were numerous issues with the methodologies used. The next 20 years of literature are a mixed bag of results, but in 1998 , Aboyoun and Dabbs performed a really interesting study where participants looked at clothed and naked pictures of people from both genders. They found that regardless of sexual preference, pupil size increased when looking at the naked pictures. They also were able to record at 2 Hz, which is a major increase in technological ability from the previous experiments. This result indicated that there is a component of general emotional arousal that affects pupil size, and it does not have to be strictly hedonic or pleasurable, which was a previous hypothesis. These results indicate that emotionally salient stimuli of any kind can increase pupil size arousal responses.

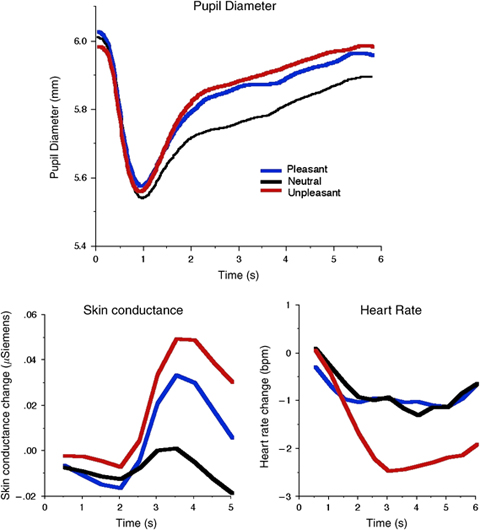
In [Steinhauer, Siegle, Condray, and Pless (2004)](https://onlinelibrary.wiley.com/doi/full/10.1111/j.1469-8986.2008.00654.x?casa_token=hgF37a4NgCoAAAAA%3A6E8Z2nwxhjd6R6116B4fxRwo_0jxrT4J-kC6HfFPyalas6C2ienosF81ziEa_7uIcqGm5pH6PKLw1g#b12), they describe the physiological system that controls the pupil and its connections to the autonomic nervous system.  There are two muscles around the eye that are influenced by activity from the sympathetic and parasympathetic systems. Activation of the sympathetic system affects the dilator muscle, which dilates the pupil, and inhibition of the parasympathetic system lessens the constriction of the sphincter muscle, reducing dilation.

**Of note:** there is some distinction between negative vs. positive stimuli. Even though both will produce an arousal response. Negative stimuli have a different process, which is mediated primarily by parasympathetic activity ([Berntson, Boysen, Bauer, & Torello, 1989](https://onlinelibrary.wiley.com/doi/full/10.1111/j.1469-8986.2008.00654.x?casa_token=hgF37a4NgCoAAAAA%3A6E8Z2nwxhjd6R6116B4fxRwo_0jxrT4J-kC6HfFPyalas6C2ienosF81ziEa_7uIcqGm5pH6PKLw1g#b3)). Of course, this implies that there may be stimuli that more predominantly activate the sympathetic system. This may have some relevance to the kinds of stimuli that we are using in Loom, but it is difficult to determine if an autistic group and a non-autistic group are perceiving the social context of a situation differently and thus activating different arousal systems. More research into this could be needed.

The final and most important piece of pupil size related arousal measurement is the system’s primary function in the response the external luminance. In a very prominent study, (Bradley et al., 2008), they attempt to control the luminance of emotional face pictures shown to participants, as to record a more realistic arousal response from the pupil. Using a combination of gray-scale, which neutralizes the effects of individual object luminance, and editing software that adjusted the overall luminance of the images, they were able to have three different degrees of luminance.

This study goes on to validate the hypothesis that arousal measured via pupil size is affected by emotionally engaging stimuli and is not dependent on hedonic-valence. [Jokiniemi, and Surakka (2000)](https://onlinelibrary.wiley.com/doi/full/10.1111/j.1469-8986.2008.00654.x?casa_token=hgF37a4NgCoAAAAA%3A6E8Z2nwxhjd6R6116B4fxRwo_0jxrT4J-kC6HfFPyalas6C2ienosF81ziEa_7uIcqGm5pH6PKLw1g#b10) validates this claim using auditory stimuli instead of visual.

Bradley et al. goes on to suggest that pupil size, heat rate and skin conductance measurement methodologies record different arousal responses depending upon the kinds of stimuli (negative vs positive). This difference in response is thought to be due to the different autonomic systems (sympathetic vs parasympathetic) that are triggered by the stimuli. A covariance between the pupil and skin conductance methods indicates that these are both predominantly controlled by activation of the sympathetic nervous system, and therefore, emotional faces are an agitator of that system. Heart rate is a better measure of stimuli that affect the parasympathetic system, which is thought to be associated with cognitive load/processing ([Steinhauer et al., 2004](https://onlinelibrary.wiley.com/doi/full/10.1111/j.1469-8986.2008.00654.x?casa_token=hgF37a4NgCoAAAAA%3A6E8Z2nwxhjd6R6116B4fxRwo_0jxrT4J-kC6HfFPyalas6C2ienosF81ziEa_7uIcqGm5pH6PKLw1g#b12)).

Of the three arousal measurement methodologies, pupil size is the only one that reacts to changes in arousal from both negative and positive stimuli equivalently compared to neutral. Skin conductance is close but seems to respond more dramatically to negative stimuli. Using pupillometry, it will be impossible to separate out the types of arousal generated from the sympathetic or parasympathetic systems. This is potentially relevant to autism research because it will not be possible to determine if the differences in arousal from this population are due to an internal processing issue or an external emotional, perceptual difference to the stimuli. In order to validate this, heart rate should be collected alongside the pupil size. If both pupil and heart rate are similarly different when comparing autistic and non-autistic groups, then we can hypothesize that the difference is generated from an upstream internal source.

This question of how arousal is being processed in autism differently is spelled out here in Mathew Goodwins review paper: <https://www.tandfonline.com/doi/full/10.3109/17518423.2014.971975>

This review posits that future research must identify specifically what stimuli are causing the differences in arousal for autistic, and if we incorporate the different arousal measurement methodologies, we can determine if it is an external or an internally relevant difference.

**Differences in types of Arousal measurement:**

In our current work with Loom v1, we have been able to characterize differences in arousal between autistic and non-autistic groups under a social context. Those differences in arousal were measured via changes in pupil size using the VR HMD built in eye-tracker. Pupil size, along with heart rate and skin conductance, are the three main methods of measuring arousal in humans. This paper (Wang et al., 2018) examines all three measurement methodologies while participants are observing emotional faces. Their finding suggests that all three are comparable forms of measurement, which is good because we are only using pupil size in our experiment.

This paper (Sirois & Brisson, 2014) is a prominent paper on pupillometry and contains a lot of really interesting techniques for analysis that I can refer back to. It also outlines the complexity of this measure in terms of what it is evaluating and the confounding variables that are possible when recording data. This paper really makes me question the validity of the measure and requires that I do more research into what this change in pupil size means. I think that I will have to come back to this question in the future. The validity of the measure is important, but right now I think I just need to focus on how arousal is affecting movement.

**Arousal and Gaze/Gross Motor Movement:**

The literature around this topic is old and also not up to date. (JB Oxendine 1970) seems to be one of the first papers talking about how the role of arousal could influence the production of movement in sports. Essentially, they wanted to know why a person who is highly attentive and engaged in something will have better performance outcomes. However, I can read the full study behind the paywall but I doubt they did any advanced measurement.

Another relatively highly cited paper that is behind a paywall but relatively newer (Beuter and Duda, 1985) reports in the abstract that higher arousal disrupts the kinematic control of the ankle joints during movement. I do not know how they measured arousal or movement, but it’s an interesting result.

**Motor Planning:**

When it comes to motor planning it is first important to discuss how basic kinematic analysis differs in this population. There is a long history of fine and gross motor dysfunction in autism (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010).

Simple upper limb kinematic studies have shown that movement in autistic children and adolescents is relatively intact. The deficits start to appear in more complex movements that require a degree of motor planning.

Motor planning is operationalized by the sections in which it can be measured.

1. Movement preparation time: the time taken to initiate movement
2. Movement execution time: defined by the temporal and spatial kinematic features of the movement.
3. Reaction time: which is the overall combination of these first two measures.

(5.5-11.8 years; Rinehart, et al., 2006a –

It study shows a very interesting result, where the autistic individuals did not have any differences in movement time (execution time), BUT they did have a slower movement preparation time. This result is found in both gross motor movement like the point-to-point task where participants moved their arm to press one of two buttons that like up, and in fine motor movements like a reach to grasp task like with (Glazebrook, Gonzalez, Hansen, & Elliott, 2009), where autistic participants failed to choose the correct grip and failed to adjust their approach position. They concluded that there was either a problem in sequencing ability, a failure to predict movement or impaired visual control of movement.

A diagram of a autism spectrum disorder

Description automatically generated