Does a universal stability mechanism exist for different forms of movement?

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Abstract

It has been shown that previous research in the area of perceptual stability has suggested that we perceive the world around us with a stability mechanism that moves objects slightly in our direction in order to perceive them as stable in the environment (a bias). This ability to accurately perceive objects is greatly affected depending on if the individual had control over their movements whilst perceiving the object. It was found that both bias and sigma (sensitivity to the object movement) was increased (higher the sigma the less sensitive participants were to the objects movement).

The current study aims to replicate such findings and expand upon them by comparing different movement types. Perceiving a rotating object has not been done in an involuntary fashion and the effects of this will be compared to see how similarly the effects are compared to axial movement of an object moving laterally through space. A correlation between the different movement types will be performed to investigate if a shared perceptual stability mechanism exists. A within participant design was used where participants completed a VR exercise that placed them in a virtual environment asking them to judge the direction of a ball. Participants completed this task by moving around the object themselves or in a specialised contraption that allowed for involuntary movement.

The findings for the study were that a successful replication of results found in previous studies was demonstrated, displaying similar bias and sigma levels for both rotational and axial movement. It was also found that similarly to previous studies that sigma and bias levels in the involuntary condition were higher, but sigma and bias values varied depending on if the ball movements were rotational or axial. There appeared to be no

significant correlation between the bias value in either the voluntary or involuntary condition when correlating both movement types. This suggests that there is no common stability mechanism for different movement types, however methodological issues are apparent.

The importance of the findings lends credibility to past research and lends evidence to a stability mechanism that compensates for the uncertainty in object movement to help individuals perceive a more stable environment. The findings for this experiment could pave the way for further research into object perception and how we perceive objects as stable. This has implications for the elderly as fall damage is more prevalent as we age and further experimentation with a similar methodology on this population may be useful for both the understanding of perceptual stability over time and how we can account for it.

Introduction

In vision research the understanding of how we interpret the moving world around us in a stable manner despite the constant sensory information from both head and eye movements has been a constant question. In a review by Burr (2004), it is showcased that a variety of possible explanations are centred around a proposed mechanism focusing upon saccades in relation to eye rotation. In one study it was shown that during the time of a saccade there are changes in the perceived visual direction that is displayed (Ross, Morrone, Goldberg & Burr, 2001). In another study conducted by Duhamel, Bremmer, BenHamded & Grad (1997), there was evidence displaying how neurons can shift their receptive retinal field in order to accommodate for head movements in relation to the position of the eye. Indeed, the perception of our surrounding environment is intertwined and dependent on the motion on our retina which arises because of the movement of the observer through space. This is a key asset of the visual system which is achieved through voluntary motor action from the observer in relation to the object they are perceiving. There is an emphasis that the movement that is demonstrated needs to be active on the part of the observer. For example, Nishijo et al. (1997) found the encoding of neurons in the hippocampus of monkeys in a spatial movement task for active, but not passive movement conditions. Another study by Snyder et al. (1998) showed that the posterior parietal cortex of monkeys encoded for neurons depending on their position in spatial frame of reference. These studies clearly demonstrate that voluntary self-movement and retinal perceptual information is vital in helping us understand how we view objects as we move around them but are also pivotal in long term learning processes. It would therefore be highly advantageous to better understand the mechanisms responsible for how we clearly see the world around us by incorporating direct information about how we use both movement and visual information. This would therefore lend itself in explaining how we incorporate such different sensory modalities and how they cooperate in helping us to perceive the world around us as stable. It would also help us in the understanding of how as we move through the world and objects move in their different trajectories how they stay stationary, not just objects but animals, other people, vehicles in our day to day life as appearing to stay fixated in our minds eye as a stable element in our world view.

It is also abundantly clear that we have an internal representation of our surroundings that rely heavily on both our movements and visual information. However, it is still not clear how we perceive a stable world when the movements given off by the observer lead to retinal motion. This can be demonstrated as we think about everyday interactions with objects, for example it is odd how we interpret an object as stable as we move around it. As we move around an object, we perceive the different angles to the object almost as if it is rotating, despite it staying stable in your perception of the environment. The apparent stability of everyday life is hard to grasp. How does our brain know that an object placed in front of us is not moving? It could easily be argued that our own rationality and interpretation could resolve such ambiguities through logic, however in situations where the environment is more ambiguous and harder to define the question persists. There may be compensation solutions that have been hard wired in us through evolution to solve the problem of the link between observer movement and retinal motion. There are in fact several compensation solutions that attempt to bridge the gap between the link of observer movement on retinal motion. These compensation solutions come in the form of different senses humans use for both vision and stability itself, the first of which is our vestibular sense. The vestibular system is part of our sensory system and provides individuals a sense of balance and spatial orientation but is also used to help coordinate movement and balance. The organs in our body which are responsible for our vestibular sense are located next to the cochlea in the inner ear, and include the sensory organs such as the saccule, utricle and three semi-circular canals. These organs are filled with fluid and have hair cells present. These hair cells respond to gravitational forces, such as head movements in order to keep balance.

Secondly, our sense of proprioception is another contributor to the possible compensation solutions that are available. This is the sense that allows human beings to perceive the location, action and movement of their body parts as they move across in space. This sense allows us to judge the distance of a limb movement and the sensations we feel as we move our body through the environment. Other useful attributes afforded to us through proprioception include the force exerted from our muscles, the knowledge of the multiple positions our body can be placed in and how heavy our limbs feel in general. The proprioceptive sense arises from sensory receptors in different parts of our body, including the skin, the muscles and the joints. It is suggested that proprioception has great importance to the control of movement through space as it places a key emphasis on where the body is placed at any given moment and our physical feelings towards its current sensations.

It has also been suggested that the efference copy sense could also be placed into this category of being a compensation solution to the problem of perceptual stability. This is the ability of an individual to create an internal copy of outward (efferent) movement. The efferent signals from the motor system are copied as they outwardly pass through the brain and are rerouted to other areas of the sensory cortex (von Holst & Mittelstaedt, 1950). This results in the individual being able to compare their actual movement with their intentional movement. This is vital as efference copies can be used to help enable the brain to predict the effects of any given action. (Jeannerod & Marc, 2003).

Lastly, our visual information is important to the stability we perceive as we move. But more specifically the optic flow that we perceive through the incoming visual information. This has risen as a possible compensation solution as optic flow is the perceived pattern of motion arising from objects in the environment caused by the relative motion between the observer performing the movements and the perceived object itself (Burton & Radford, 1978). It has been suggested that the brain parses retinal motion into components arising due to observer and object movement and uses its sensitivity to optic flow to achieve such activity (Rushton & Warren, 2009). This could be a key compensation solution in explaining the link between retinal motion and movement. However, despite these numerous compensation solutions in explaining perceptual stability, the extent to their involvement is unclear.

There have been numerous experiments that have attempted to answer how we perceive perceptual visual stability more directly. Firstly, Wallach, Stanton & Becker (1974), yoked the movement of an object to the movement of an observer. This meant that as the observer moved around an object, they rotated the object with them to varying degrees. In Wallach et al's (1974) experiment they used a mechanical apparatus attached to a helmet worn by the participant to a target object through a ratio gear mechanism. This contraption allowed for the experimenter to change the degree to which the object rotated with the participant and in which direction the object would rotate (this is known as the gain). For example, with a gain of 1, the target object rotated as to always display its face towards the observer, with a gain of -1 the object rotated by an equal and opposite amount. A gain of zero showcased the object in a stationary position and not moving at all. In Wallach et al's (1974) study participants were asked to move around a rail system whilst observing the object, this consisted of 2 passages of which was made of three trials. Participants were then asked after observing the movement of the object if the object had rotated or not and in what direction. They found that a gain of as much as +0.45 was tolerated before observers reported that the object had moved. This amount of gain required is known as the "bias", this is defined as the point at which the individual was maximally indecisive about whether the object was moving in the same direction or in the opposite direction against themselves and is therefore taken as the point at which they perceive the object to be stationary.

In an updated version of this experiment by Tcheang, Gilson and Glennerster (2005) they had repeated the aims of Wallach et al. (1974) and examined the role of visual information in determining the perception of an object as static in the world. They improved on Wallach et al's (1974) original study by expanding the original experiment by using an immersive virtual reality system. This is advantageous as it allowed for the participant to perform much more free moment to explore the scene naturally in relation to the target object. The observer was not directly tied down to a mechanical apparatus to perform the experiment and allowed the experimenters to have more flexibility to yoke movements of the target object to certain components of the observer's movements. Participants were asked to move side to side whilst viewing an object whilst it rotated to varying degrees of gain. The gain procedure was like that of Wallach et al's (1974) experiment with gains varying between +1 and -1 with a stationary object at a gain of 0. A key difference in this study however was the fact participants were asked to decide if the rotating ball was moving "with" them or "against" them. This response system works in relation to the gain parameters that are set, for example, a gain of +1 will always show the face of the object to the participant and would therefore move "with" them, and a gain value of -1 would always move the face of the object away from the participant and would therefore move "against" them. A gain of 0 would once again mean that the ball was stationary, if participants could not decide what direction the ball was moving, they were asked to give their best guess. In Tcheang et al's (2005) experiment a positive gain of between +0.25 and +0.45 was found for four separate participants. This small positive bias is similar to that of Wallach et al's (1974) original experiment.

In a separate experiment conducted by Wexler (2003) a similar methodology of yoking an objects movement to a participant's movement was used to investigate perceptual stability for axial (forward and backward) movements as the object (which was a ball) translated in space, rather than make rotational movements as seen earlier. In a similar manner to both Tcheang et al. (2005) and Wallach et al's (1974) experiments they varied the gain of the object as the participant made relevant forward and backward head movements in order to perceive the object. Participants were asked to judge whether the object moved in the same direction as their head movement or in the opposite direction. A key difference in Wexler's (2003) experiment was the interest in the difference in perception produced by voluntary and involuntary moment by the observer. It was found in Wexler's (2003) study that a mean bias of +0.38 for the participant to view the object as stationary, however this was seen as the participant made voluntary movement toward the object. A higher mean bias of +0.57 was found when required to complete the same task, but the participant's movements controlled by the experimenter. The experiment by Wexler (2003) is interesting as it focuses on voluntary and involuntary movements which link to the compensation solutions that were mentioned earlier, including vestibular sense, efference copy, proprioception and visual information (optic flow). The compensation solutions are the self-movement information type (SMIT) that the participant has access towards. As a higher bias value is found in the involuntary condition it could be because of the removal of certain SMIT senses. Whilst performing the involuntary condition Wexler (2003) instructed participants to complete the same perception task but required them to sit on a wheelchair as he pushed the participant along to make the necessary forward and backward movements. The SMIT that is missing from this involuntary movement condition is the efference copy. This led to a higher bias, meaning that the object had to move as much as a gain of +0.57 before reporting it as moving. It was also found that the sigma value, or participants sensitivity to the ball movement was higher in the involuntary condition compared to the voluntary condition. A higher sigma indicates less sensitivity to the target stimulus. This is unsurprising as the less senses available led to less sensitivity in their ability to perceive the object and therefore showcased a higher sigma value. This also demonstrates to what extent other senses, such as proprioception, vestibular sense or the need for optic flow have in the need for perceptual stability. As the removal of the efference copy SMIT has shown to increase bias, so our mechanism for perceptual stability must compensate with a higher level of both bias and sigma. It has been suggested by Gogel (1990) that an observer's perception of their own position in space is critical to visual perception. Therefore, it would be useful to incorporate the different types of non-visual senses that are employed in object perception.

The current study firstly aims to replicate the findings in recent perceptual stability experiments from both Tcheang et al. (2005) and Wexler (2003). The main interest of this study is to observe if the effects observed in previous studies will be preserved in a completely different group across different self-movement types, and how this is affected by the presence of different SMIT conditions. If consistent results with past experiments are displayed it lends credibility to the research area by further improving upon past experiments with the integration of more modern and precise technology and equipment. If this is not possible further investigations will have to be taken to understand the full extent to which self-movement types and SMIT impact how we perceive stability in our everyday life. The replication of both studies would be especially important considering the small sample size in both experiments. The Tcheang et al. (2005) paper for instance, had a sample size of four participants. Wexler (2003) managed to provide eleven participants. Both sample sizes are relatively small, and it would be useful to collect a larger sample size to get a better idea of the bias and sigma values and compare the collected results with the past experiments. As a result, replication of their experiments will allow us to test the validity of their findings.

The secondary aim of this study is to expand upon previous research and further investigate the accuracy and precision of the mechanism that supports perceptual stability. In order to achieve this an understanding between the relationship between different movement types will be conducted. In particular, we will investigate the bias value's relationship between the movement types specified in previous experiments which include the rotational movement type and the axial movement type. The investigation of whether there is a relationship between both movement types could test if there appears to be one mechanism that underpins perceptual stability over different movement types, or if there are different mechanisms for different types of movement. This is interesting as Chang et al. (2014) has demonstrated that older individuals decline in their ability to maintain visual stability. It would therefore be important to understand the relationship between different forms of movement regarding object stability to gain a more complete understanding of perceptual stability.

Lastly, the current study will expand upon Wexler's (2003) methodology of removing SMIT senses from participants but for the rotational movement condition as well as the original axial movement. It has been suggested by Gogel (1990) that an observer's perception of their own position in space is critical to visual perception. Therefore, it would be useful to understand the impact of the removal of certain SMIT senses on the other types of self-movement. This will therefore allow for the understanding of how the removal of certain SMIT senses impacts the stability of object perception by combining variables of of voluntary movement, as seen in Wexler's (2003) study and the rotational movement self-movement information type as seen in Tcheang et al's (2005) study. This is in conjunction with the original Wexler (2003) axial movement condition. This combination of different ball movement types in conjunction with the involuntary SMIT condition is unique to our experiment and the removal of certain SMIT senses on the rotation condition has not been demonstrated previously.

The experiment we will conduct in order to achieve our aims will employ a virtual reality (VR) system to manipulate the movement of the target object. This will be displayed on our retina via a VR headset and will be relative to the participant's voluntary movement. The participant will be free to move around the object as they view it meanwhile the experimenter will manipulate the movement of the object to allow for relevant yoking of the target object to allow for the experiment to commence. In the VR environment we can alter the motion of the object, so it rotates or moves laterally away from the participant to a greater degree than that which is expected by everyday observations of similar objects. In the current experiment, similarly to Tcheang et al (2005) and Wexler's (2003) studies there will be an effort to collect measures of both bias and threshold (sigma). We also plan to expand the VR experiment conducted by Tcheang et al. (2005) by providing a means as to complete the rotational object movement condition with an involuntary movement method. The study that is proposed will fill a gap in the literature by allowing participants to undergo different movement types in conjunction with different SMIT conditions by observing their performance in an object perception task in both voluntary and involuntary conditions. These consequent results would allow for a more comprehensive understanding of how we perceive objects as stable in our environment.

It is hypothesised that participants will demonstrate a small positive mean bias and sigma values that are similar to that which was demonstrated in both Wexler (2003) and Tcheang et al’s (2005) commensurate conditions. It this is the case; we also hypothesise a positive correlation in the bias measure between the axial and rotational object/observer movement types. This is predicted to be true for both voluntary and involuntary movement types. The rationale behind the investigation for such a relationship is the search for a common stability mechanism that accounts for the stability of different movement types. It is also hypothesised that involuntary conditions that have less SMIT information will demonstrate a higher level of bias in comparison to voluntary conditions. It is also hypothesised that participant’s threshold levels (sigma) will display a significantly higher level of sigma for the involuntary condition when compared to the involuntary condition for the same reason. The direction of these hypotheses is based on Wexler’s (2003) findings for both bias and sigma values for the axial movement condition in both the voluntary and involuntary movements.

Method

Participants

The current study used 16 participants between the ages of 19 to 25 years old. They were recruited through a volunteer sampling method through poster advertisements placed throughout the University of Manchester campus and a snowballing sampling method. The participants were compensated for three hours of their time with a £15 high street voucher. All participants had normal vision acuity without correction.

Equipment

The virtual reality (VR) system consisted of an HTC Vive VR display, fitted with a head tracker and a Zotac Go gaming PC to help render the virtual world in order to generate the appropriate images for the experiment to proceed. The position and location of the participant's head was tracked by using a native tracking software that is present with the HTC Vive. Information from the tracking software was used in conjunction with "Motive" which is software system that allows for the 360-degree tracking of the participant to allow them to move freely in relation to the computer-generated image presented through the headset. The HTC Vive (HTC and Valve Corporation) head mounted display unit presented a separate 1080 x 1200 pixel image to each eye using Pentile OLED displays.

The virtual stimulus presented to the participant was generated using the Vizard VR application which uses the Python programming language to help generate the appropriate image. The image presented to the participant was that of a football which was black and white patterned. An Xbox 360 controller was used to record participant's responses. The

Xbox 360 controller was connected to the Zotac Go gaming PC through the use of a wireless dongle that was connected to the USB port. The right trigger of the Xbox 360 controller was mapped to the participant's "with" response and the left trigger was mapped to the participant's making an "against" response.

In order to direct the involuntary movement of the participant a customised chair was built complete with a movement track (as seen in figure 3). This consisted of a modified office chair that can be adjustable for both side to side movement and forward and backward movement. The chair could be locked into place to allow for smooth movement without any shaking or odd movements. The chair was engineered onto a platform which had wheels that would allow the platform to be placed on top of the rail system for use when the involuntary condition was underway. The rail system was rotated horizontally and vertically to be able to accommodate the passive conditions of both movement conditions. The chair itself could be rotated on the platform 45 degrees to be able to adjust to the direction of the needed condition. Doorstops were placed on the wheels of the platform to be used to stop any unnecessary movements of the chair on the rail system, but also for health and safety reasons to avoid unnecessary risk to the participant when getting on and off the chair.

Experimental Design

The first IV is the object/observer movement which is the type of object orientated movement exhibited by the stimulus ball and the participant's associated movement in relation to the object movement. This comes in two levels: the first being rotational movement by the object and the associated side to side movement exhibited by the participant. The second level to this IV is the axial movement by the object in space coupled with the lateral forwards and backwards movement performed by the participant (as seen in figure 2).

The second IV is the self-movement information type (SMIT) available to the participant. This also comes in two levels; voluntary movement where participants have full access to all four of their SMIT senses, including their visual sense, efference copy, proprioception and vestibular senses. The second condition is the involuntary condition where participants had access to only half of the previous SMIT senses mentioned earlier. The SMIT senses unavailable to them in the involuntary condition include the efference copy sense.

There are two dependent variables (DV) of interest int his study. Firstly, the participant's level of "bias" which is the objective point at which the object is stationary and when the participant subjectively viewed the object as stationarity. This is dependent on the level of gain added to the object before the participant viewed the object to move "with" them. Secondly, the "threshold" measurement (sigma), which is the participants level of sensitivity to changes in the gain of the stimulus. A lower threshold indicates a faster ability to detect changes in the gain of the stimulus. Both the bias and sigma will be recovered using a psychometric 2 AFC procedure detailed below in the analysis section.

A within subject's design was conducted as participant's completed all conditions in each of the two independent variables (IV). During the experiment participants were counterbalanced as to which SMIT condition they would perform first.

Stimulus and procedure.

After entering the VR laboratory participants will be told the health and safety warnings such as dizziness, nausea and so on from using the VR equipment. They will complete the relevant documents and shown a bucket they can use to throw up inside in case they feel too sick during the experiment. The experimenter will place the VR equipment on the participant and will show the participant a demo to help familiarise them with the VR equipment and the virtual environment. Participants will observe a Spanish plaza and be instructed to move around freely in the virtual scene. Participants are notified by the experimenter when they approached an obstacle in the real world that could obstruct their movement. Participants were directed to the middle of the plaza and instructed to focus on the fountain ahead of them. As they focused on the fountain the experimenter centred the screen for a more accurate viewing experience. Participants were asked to move around in the plaza until they felt comfortable in the VR environment.

The conditions in which participants would complete each SMIT IV were counterbalanced. This was decided by splitting the participants into two groups, so the first eight participants completed the voluntary condition followed by the involuntary condition and the following eight participants completed the involuntary condition followed by the voluntary condition.

In the voluntary condition participants were placed behind a table to help give them a reference for how to move relative to the target object. Participants were told to stand on a marker to help centre their field of view. The participant was then instructed by the experimenter on how to make the correct movements. This included the side to side movement necessary for the rotating stimulus condition, which involved spreading their legs a shoulder width apart and for the participant to sway side to side in time with a metronome which went at a speed of 40 beats per minute. The experimenter asked the participant if they were ready to begin the task. If the participant answered “yes” the experimenter would centre their field of vision so that it was centred to the stimulus object and the experiment would begin. In the virtual environment, participants view a virtual football (20cm diameter) at 1.8m from their starting position. Participants were asked to look directly at the ball and make the necessary movement to help them perceive the ball accurately. Participants were asked to focus on the ball and move their head whilst making the instructed movements so that the ball remained in the centre of their field of view. The participants are tasked to judge whether the ball moves “with” or “against” them as they perform the instructed movement. The “with” and “against” movement is identical to that described in Tcheang et al’s (2005) study where each response corresponds to the relevant gain value. The participant would then give the correct “with” or “against” responses on the Xbox 360 controller in response to the stimulus presented in front of them. After participants had recorded the computer-generated ball would disappear. After a half a second delay the ball would reappear. The ball has no specular properties that would allow for the participant to detect extra moment. A practice session was given to the participant in order to familiarise themselves with the task in hand. The practice session consisted of 6 trails that primed the participant for either the rotation or axial movement condition. The trails were designed to be straightforward and easy to follow so the participant could understand what the experimenter meant when they asked if the ball was moving “with” or “against” the participant. For example, in the first trail the ball had a gain of +1, and the experimenter would explain that as the stimulus ball continuously showed its face to the participant it would need a “with” response. The next trail had a gain of -1, and the experimenter would explain that as the stimulus ball did the opposite movement from the first trail this would elicit a “against” response. The third trail had a gain of 0 so this made participants unsure if the ball was moving “with” or “against” them, so they were asked to make their best guess. This third trail was to prime them for the uncertain gain conditions they would later face in the actual experiment. The previous 3 trails were repeated to make the rest of the trails in the practice block. This whole practice procedure is repeated for the axial movement condition to help participants understand the correct “with” and “against” responses for that object/observer movement condition. After the practice trail participants engaged in the actual experiment. The participants were required to complete 3 blocks of trails for each ball condition. A block consisted of 20 trails. Participants had to repeat this for the passive and active movement conditions respectively. Altogether participants completed 12 blocks of trials. The experiment requires three hours to complete all blocks of trails. Participants were then instructed on how to perform the correct movements for the axial ball movement condition. Participants were instructed to place their feet in front of one another at about a shoulder width apart. They were then asked to make the correct forward and backwards swaying motions to allow them to perform the task accurately and perceive the stimulus correctly.

Depending on the ball movement condition participants viewed the target ball as either rotating around a vertical axis (where the centre point remained stationary), as the participant moved side to side. This was the first level for the object/observer IV. In the second level for the same IV, participants moved forwards and backwards in relation to a ball which was displacing its movement on an axial path. In both levels the amount of rotation and axial movement made by the object was linked to the participant's movement by different gains on each trail. A gain of 1 in the rotation movement condition made it so that the sphere rotated as to always show the face of the sphere to the participant. A gain of -1 in the same condition would do the opposite, in that that it would give an equal and opposite rotation as to always move the face of the ball away from the participant. In the axial movement condition, a gain of 1 would present the ball as always following the participant, for example as the participant moves forward the ball would mimic their movement in a one to one manner, the same would be displayed for backward movement. A gain of -1 in this condition displayed the ball doing the exact opposite of the participant, so as they move forward, the ball would move backward, and if they moved backward the ball would move forward. When the sphere demonstrated a gain of zero it remained static and unmoving in both conditions. In both conditions the balls level of gains varied between the two extremes of 1 and -1 (See figure 2).

The range of gains for each block would be determined by the participant's input on the initial trails. The trails would start with a gain of -0.7 and 0.7 and get progressively harder or easier depending on their level of accuracy. The gain parameter on each trial was controlled by an adaptive staircase procedure (using the KEsten staircase – Treutwein, 1995). There was an interleaving of two such staircases in each experimental block. The first started from a large positive gain and converged at the point on the psychometric function at which participant responded that the ball was moving with them on 20% of the trials. The second started from a large negative gain and converged on the 80% point on the psychometric function. Throughout the experiment the gain level was closer to or farther away from the stationary gain value of 0 depending on the participants level of correct responses. For example, if the participants made several errors it would make the ball easier to discriminate by placing it closer to a gain of 1 or -1, and if they made correct interpretations of the balls movement it would become harder and closer to 0 and therefore harder to discriminate. This approach yielded good coverage of the region around the point of subjective equality (PSE) for all participants.

After completion of the voluntary condition participants then redid the experiment but in the involuntary condition. In the involuntary condition the experimenter moved the platform to the end of the rail system and locked it in place with the use of two door stops for each of the wheels on the platform. The involuntary SMIT condition can be displayed in figure 3. The experimenter then asked the participant to step on the platform and sit down on the chair. The participant was then secured onto the chair and asked if they felt comfortable. The participant was instructed not to leave the chair unless the experimenter explicitly asked them to for health and safety purposes. After placing the participant on the chair, the experimenter then moved the platform along the rail and centred the participant on a marker on the floor which displayed the centre point to the experiment. Participants were then fitted with the VR equipment and again asked to look forward at the ball stimulus in front of them. The participant was then given the Xbox 360 controller and asked to repeat the task of responding on the controller if the ball was moving “with or “against” them. The experimenter pushed the participant side to side in time with the 40 beats per minute metronome. The distance the experimenter pushed the participant was roughly shoulder width apart similarly to the voluntary SMIT condition. After completing the rotational object/observer movement condition the participant was asked to remain seated as the platform was moved to the edge of the rail system. Again, the doorstops were used for health and safety purposes on the wheels of the platform to stop it from moving as the participant got off the chair and off the platform. The rail system was then rotated 45 degrees in order to facilitate the movement of the involuntary condition SMIT condition where lateral movement was needed to perceive the ball moving in its axial path moving forward and backward. In conjunction with this the chair that is fitted onto the platform would also rotate 45 degrees so that the platform could be adjusted to sit the needs of the rail system. The chair would be fitted into its new position. Yet again, the platform would be pushed to the end of the rail system and secured with doorstops. The participant would be asked to step onto the platform and sit on the chair. The participant would then be asked to repeat the experiment for the axial observer/object condition. The experimenter would in this instance time the forward and backward movement of the participant to the 40 beats per minute they will be hearing on the metronome. The participant was yet again pushed about a shoulder length apart similarly to the distance they moved in the voluntary movement condition. After completing the experiment, the participant would be rewarded for their time with the promised high street voucher.

Analysis /Assessment of the data

To recover bias and thresholds for each condition we fitted a cumulative Gaussian psychometric function to the data obtained using the Palamedes toolbox for MAtLab (Prins & Kingdom, 2019). The point of subjective equality (PSE) was defined as the point at which the participant was maximally indecisive about whether the ball was stationary or moving in the respective ball movement condition. The PSE was used to characterise the bias. The bias displays the rotational gain at which the participant perceives the ball to be stationary as they move. The threshold was taken as the reciprocal of the slope of the psychometric function (or equivalently the standard deviation of the underlying cumulative Gaussian psychometric function).

In order to understand if we successfully replicated Wexler (2003) and Tcheang et al's (2005) a one sample t-test is conducted. The one sample t-test allows for the observation of our bias and to see if the bias obtained in the experiment differs from a mean of 0. The hypothesis here is that results from the one-sample t-test will provide a bias and sigma value significantly different from 0 and the experiment will replicate the positive bias seen in both Tcheang et al (2005) and Wexler's (2003) experiments.

A 2 x 2 repeated measures ANOVA would be conducted to compare across conditions in our two IVs. Firstly, it would demonstrate the main effect of the ball movement condition (rotation and axial movement). Secondly, it would show if there is a main effect for SMIT type (voluntary and involuntary conditions). This analysis would also provide interaction effects in relation to both IVs which could prove to be important in interpreting our data. If the hypothesis is correct, we will expect a main effect for SMIT type. As a result, this would show a lower bias and lower sigma value in the voluntary condition in comparison to the involuntary condition.

Lastly for our analysis, a Pearson's correlation coefficient is performed to investigate the relationship between the bias values between the different object/observer movement types. This will test our hypothesis of a common mechanism underlying visual stability.

Ethical considerations

Ethical approval for the experiment was obtained from The University of Manchester. Participants filled out a form that confirmed their informed consent to partake in the experiment. This form contains information regarding the purpose of the experiment and how the researchers will use the participants information to achieve their aims. The form also contained details about the researchers and how they can be contacted. Potential factors that could induce feelings of uncomfortableness, such as motion sickness and nausea was made aware to participants both on the information sheet and before they were provided with using the VR equipment. After the research is completed participants were able to discuss the procedure and research aims with the researchers. The participants were given a general idea of what the researcher was investigating and why, and how their part in the research will be explained and taken forward in the furture.

The protection of the participants mental and physical wellbeing when partaking in the VR experiment is a huge consideration. Participants were allowed to stop the current VR exercise that was being performed if they felt uncomfortable. Participants are also allowed to withdraw their data if they felt like they cannot continue with being in the VR environment, is this was the case participants were still given their vouchers for partaking. Participants data will be kept anonymous. No names will be used in the research report.

Results

Descriptive statistics for the bias and sigma values obtained from the experiment are displayed in table 1. This shows the average mean and standard deviation across our first IV, the object/participant movement and our second IV the SMIT condition. Both levels of each IV are displayed including the results for the rotational and axial movement conditions in our first IV and the voluntary and involuntary movement condition in our second IV.

Table 1. *Descriptive statistics for participants responses for all conditions*

	M (Bias)	*SD* (Bias)	*M* (Sigma)	*SD* (Sigma)
Voluntary Condition				
Rotation	0.17	0.22	0.26	0.12
Axial	0.15	0.21	0.24	0.1
Involuntary Condition				

Rotation	0.26	0.23	0.38	0.25
Axial	0.28	0.23	0.32	0.12

Note: *M* = mean, *SD* = standard deviation

A one sample t-test was also conducted in order to test if a statistically significant difference existed between bias and sigma scores from the sample used in this study and a population who did not exhibit any bias or threshold that was different from the value of 0. If statistically significant results existed this would be consistent with Wexler (2003) and Tcheang et al's (2005) experiments and would demonstrate their studies being successfully replicated. Table 2 displays the t-statistics and significance values for our bias measures in the one sample t test. Table 3 shows the t statistics and significance values for our sigma measures when conducting a one sample t test. The overall results across both bias and sigma values returned results from the one sample t test that were all significantly different from 0 ($p < .005$).

Table 2. *One sample t-test results for bias measures*

Object movement/ SMIT conditions	*t*-statistic	*p*
Rotation/Voluntary	3.07	< .005 *

Axial/Voluntary	2.87	< .005*
Rotation/Involuntary	4.64	< .005*
Axial/Involuntary	4.75	< .005*

Note: * indicates a significant value

Table 3. *One sample t-test results for sigma measures*

Object movement/ SMIT conditions	*t*-statistic	*p*
Rotation/Voluntary	8.64	< 0.05*
Axial/Voluntary	9.36	< 0.05*
Rotation/Involuntary	5.91	< 0.05*
Axial/Involuntary	10.40	< 0.05*

Note: * indicates a significant value

A two-way ANOVA was conducted to replicate the findings seen in Wexler's (2003) study regarding involuntary SMIT condition having a higher bias and sigma value compared to voluntary conditions. Two ANOVAs will be conducted for bias and sigma respectively. The ANOVA will also allow us to see new insights to weather differences are seen between both object/observer movements and if there is an interaction between object/observer movement and SMIT conditions. The descriptive statistics show a smaller mean bias for both axial (M = 0.17) and rotational movement (M = 0.15) in the voluntary SMIT condition when compared to their involuntary counterparts (M = 0.26, M = 0.28). The same is true for the mean sigma values for both the axial (M = 0.26) and rotational (0.24) movements in comparison to the involuntary SMIT equivalents (M = 0.38, M = 0.32). In order to test the hypothesis SMIT condition (voluntary or involuntary) had a significant effect on both bias and sigma results a within-groups ANOVA was conducted.

The within-groups ANOVA for bias measures presented results that were not significant for the main effect of object/observer movement, $F(1, 15) = 0.00$, $p = .949$, ges = .000. There was also no significant interaction between the two IVs of object/observer moment and SMIT condition, $F(1, 15) = 0.24$, $p = .632$, ges = .002. However, the main effect of SMIT condition was statistically significant, F (1, 15) = 11.63, $p = .004$, ges = .063. Thus, the null hypothesis of there being no difference between the SMIT conditions of voluntary and involuntary movement is rejected. To evaluate the nature of the differences between the means of the two SMIT conditions a post-hoc test was carried out.

The post-hoc test found no significant difference between voluntary and involuntary SMIT conditions in the rotation object/observer movement type, t (29) = -1.79, $p = .084$. There also existed no significant difference between voluntary and involuntary SMIT conditions when the voluntary movement was the rotation movement and the involuntary condition was the axial movement, t (29) = -1.87, $p = .073$. There was significant difference between voluntary and involuntary SMIT conditions when the voluntary movement was the axial movement and the involuntary movement was the rotational, t (27) = 1.98, p = .059. However, the difference between voluntary and involuntary SMIT conditions was significantly different when comparing the axial movement condition in both SMIT conditions, t (29) = -2.55, p = .017.

The separate two-way ANOVA that was conducted to investigate sigma values between conditions found no significant main effect of object/observer movement type F(1, 15) = 0.99, p = .335, ges = .017. There also was a display of no interaction between object/observer movement and the SMIT condition participants completed, F(1, 15) = 0.35, p = .564, ges = .003. However, it was found that a there existed a main effect of SMIT for measures of sigma, F(1, 15) = 6.28, p = .024, ges = .089. A further post-hoc test was conducted to further analyse the means between the different SMIT conditions.

Post hoc tests for the sigma values when comparing SMIT conditions found no significant difference between SMIT conditions when both object/observer movement type was axial, t(28) = -1.65, p = .109. There also existed no significant difference between SMIT conditions when the voluntary movement was axial and the involuntary movement was rotation, t(30) = -1.00, p = .324. The significant differences in means were shown whilst comparing voluntary and involuntary SMIT conditions where both object/observer movements were rotational, t(28) = -2.36, p = .026. There was also a significant difference between voluntary and involuntary SMIT conditions when the voluntary condition was axial movement and the involuntary condition was rotational, t(27) = 1.15, p = .269.

To test the hypothesis that there may be a common stability mechanism between different movement types a Pearson's correlation coefficient was performed on the bias measure for both voluntary and involuntary SMIT conditions. The correlations found no significant correlation in the voluntary SMIT condition between rotational and axial movement, $r(14) = .24$, $p = .372$. There was also no significant correlation between the two object/observer movements when correlating bias in the passive SMIT condition either, $r(14) = .49$, $p = .053$. The hypothesis was therefore rejected. Graphs for the correlation coefficient can be see in figure 1.

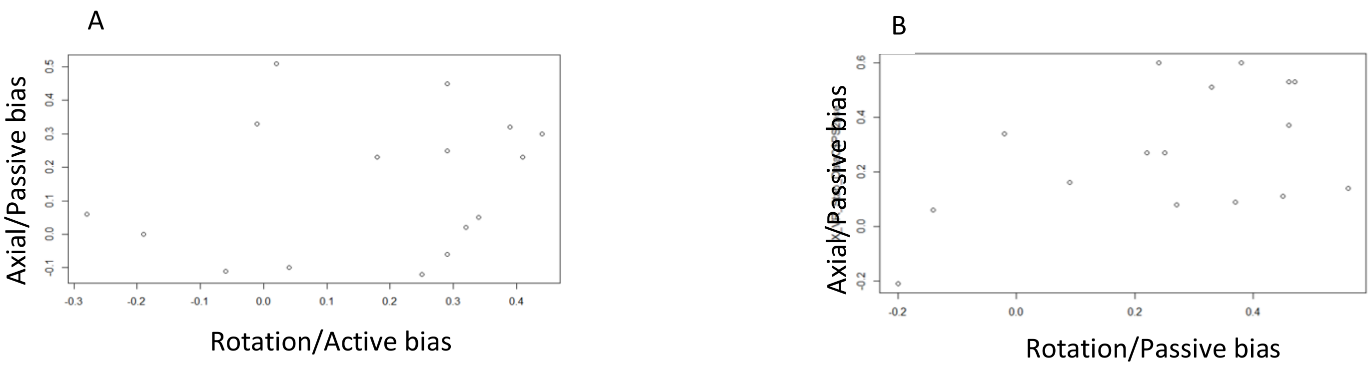

Figure 1 – (A) Displays the correlation coefficient for the active condition for both rotational and axial observer/object movement conditions, r(14) = .24, *p* = .372. (B) Displays the correlation coefficient for the passive condition for both rotational and axial observer/object movement conditions, r(14) = .49, *p* = .053

Discussion

The collection of the data in the current empirical research have given a mixed finding in relation to the research topic of stability perception. The first hypothesis stated that we would produce a positive bias in results consistent with that of Tcheang et al. (2005) and Wexler (2003). This hypothesis was accepted, and the null hypothesis was rejected. This was shown as the one sample t-test results are consistent in that a positive bias and sigma value was demonstrated for all possible combinations of both IVs. This has therefore demonstrated a successful replication of both Tcheang et al's (2005) and Wexler's (2003) past experiments by displaying a value larger than 0 (see tables 1 and 2). This also adds credibility to the initial idea proposed by past studies by experimenters such as Wallach (1974) that objects must move a little in the same direction as the observer in order to be perceived as stationary. The greater sample size and the updated methodology used gives greater validity to the idea of an internal mechanism that individuals use to help perceive their everyday life as stationary.

The hypothesis that there would be both a higher bias value and a sigma value for involuntary SMIT conditions compared to the voluntary counterpart was also accepted. The null hypothesis was therefore rejected. The use of a within-subjects ANOVA demonstrated that participants in the involuntary SMIT condition had significantly higher bias and sigma values for both axial and rotational movement. This is consistent with Wexler's (2003) study but expands upon it by showcasing a similar increase in bias and sigma for the rotation condition, which was previously not performed. Upon closer inspection of the post-hoc tests performed that were a mixed set of results on display. There only appeared to be a significant difference in bias between voluntary and involuntary SMIT condition only when the object/observer condition was axial. No significant difference in bias was seen in the rotation condition. In terms of the sigma value, it was found that a significant difference was displayed for the rotation condition of the object/observer IV, but not the axial condition. This suggests that although our initial hypothesis is accepted as the general means between each IV may have been different, when comparing the conditions individually there may not have been a difference between SMIT conditions under specific object/observer conditions. This is somewhat consistent with Wexler's experiment in that the axial condition that was conducted in his paper yielded similar bias values in the voluntary and involuntary SMIT conditions, however the sigma values are not consistent as there is not a large enough difference between the values. It is also problematic as there was no significant difference in bias for the rotational condition when comparing SMIT conditions, but there was a significant difference in sigma which would be expected. Possible explanations for such a variety of results that are inconsistent with Wexler's previous findings is that there may be a separate stability mechanism in place for both rotational and axial movement of objects and therefore leads to varying levels of bias and sigma depending on the type of stimulus movement that is being observed. On the other hand, the reason for this inconsistent result may be because of the small sample size that was collected. The initial number of participants that were expected to be recruited was 20, however due to time constraints the current study was only able to recruit 16 participants. The lack of range in our data could have caused the lack of significance in our post hoc tests. Another possible problem with the data collected is the possibility of a difference in perception of the object itself as the participant was making movements. Indeed, it has been demonstrated that sitting down can alter your senses for such activities as tasting and smelling food (Biswas, Szocs & Abell, 2019). This study has shown that standing up places stress on the vestibular system, which is one of the SMIT senses that is present in both the voluntary and involuntary conditions. This is problematic as the extent to this loss of ability in the vestibular sense is not accounted for in the context of this visual stability experiment. Future experiments need to take into consideration a possible alternative to either the voluntary SMIT condition or the involuntary SMIT condition by either thinking of solutions in which the participant is either sat down or stood up in both SMIT conditions.

One of the two main senses that was removed in our involuntary SMIT condition was the efference copy sense. There did appear to be some difference when it was removed, but further investigation is needed to see the extent to which the removal of this sense impacts our visual stability. But an effect has been demonstrated and practical application to this knowledge could be possible, for example the elderly is at a higher risk of falling over and injuring themselves (Stellmach & Worringham, 1984). This is in part due to problems with deficits to their motor system. As efference copy is part of the motor system it could be assumed that elderly citizens have a deficit in this key sense for stability. This could explain their increased likelihood to suffer from fall damage as they find it harder to perceive their world and the moving objects in it as stable. It would be reasonable to assume that the elderly, who may possibly have a reduced ability in their efference copy sense, could display a larger bias for perceive objects as stationary. This assumption is based on the findings of the current experiment. The potential ramifications of having a larger bias in the elderly population could be linked to a longer processing time needed for them to accurately judge the distance and properties of an object. This is problematic for their perceptions of stability in the world. This idea can be expanded upon to the elderly also potentially having a higher sigma value. If the assumptions about the elderly having a poor efference copy sense is true we would expect them to also have a higher sigma value and therefore make them less sensitive to changes in the movement of an object. The low sensitivity to object movement change could also lead itself to an increased likelihood of fall damage for the elderly. In order to test this idea future studies should replicate the voluntary SMIT condition for either object/observer movement type between young participants and elderly participants. It would be interesting to observe how the elderly participants compare to the young participants (aged 19-25 similarly to the current study). It would also be interesting to see if elderely participants show similar larger bias and sigma values as the young participants in the involuntary SMIT condition. If this was the case it would lend credibility to the idea that the reduction in efference copy sense leads to less stability in the elderly. The conduction of this experiment would lead to a greater understanding of ageing and how it impacts how it impacts the stability of our world over time.

Another recommendation for future research is to introduce a completely visual element to the study. The use of VR allows for movement without the use of voluntary or experimenter led movement. Participants could simply sit in the chair and input their responses whilst a computer-generated movement leads them. This would be useful as it would measure the extent to how useful purely visual information would be to perceptual stability, but also how detrimental losing senses such as proprioception, vestibular and efference copy would be to visual stability. It would also be useful to understand how simply one of our senses, the visual sense which provides important information such as optic flow factors into our ability to perceive a stable world. This would be interesting when coupled with the different movement types that have been showcased in this study.

Lastly, the final objective that was the be investigates was the idea of a common stability mechanism that underlies stability for different movement types. The Pearson's correlation coefficient of the bias measure outputted a correlation that was insignificant for both the voluntary and involuntary SMIT conditions when comparing either rotational or axial object/observer movement type. This does suggest that there does not appear to be a common stability mechanism. Indeed, there may be separate internal perceptual systems that our brain uses in order to perceive stability between both the rotational movement and axial movement of an object. However, it could also be suggested that our sample size was not large enough in order to carry out a rigorous correlation. Indeed, it has been suggested by David (1938) that a sample size of at least 25 participants is required for an adequate correlation analysis. If this is the case a relationship between the variables may be present, this is especially likely as the probability value for the passive SMIT correlation was bordering on significance.

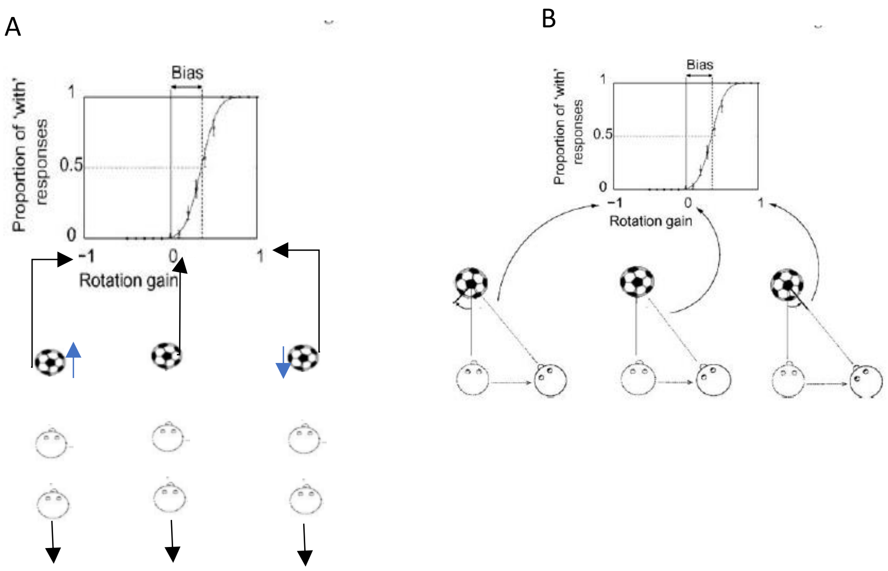

Figure 2 – (A) represents how the axial object/observer condition corresponds to the relevant gain value. (B) displays how the rotation condition corresponds to the relevant gain values. Both graphs are adapted from Tcheang et al. (2005).

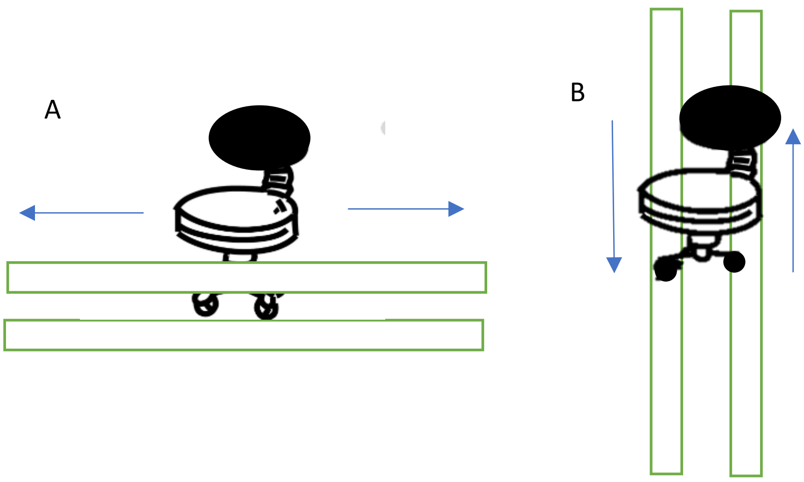

Figure 3 – A recreation of the contraption used to perform the involuntary SMIT condition. The Zotac Go gaming PC would be placed to the side of the participants with all wires away from the rails. The green bars represent the rail system. (A) Represents the movement that would be performed by participants performing the rotational movement task, (B) would represent participants who were undergoing the axial movement task.

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