The Relationship between the "Vision for Action" Pathway and Accident Vulnerability

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Abstract

Visual processing in the brain is comprised of two pathways. The ventral stream processes vision for perception, which helps to make sense of what is in the visual field. The dorsal stream processes vision for action, which enables navigation through the spatial environment and spatial relationships. When the dorsal stream acts effectively, individuals can avoid bumping into things, dropping things, tripping over, and other vision-related accidents. This leads us to the question, is accident proneness related to dorsal stream functioning? In phase one, the Accident Proneness Questionnaire (APQ) was used to measure individuals' self-reported tendency to be involved in accidents. In phase two, a subset of questionnaire respondents was tested in a computer-based Vision for Action Test (VAT), designed to assess participants' ability to respond to peripheral stimuli as a correlate of dorsal stream functioning. The APQ proved a consistent and reliable measure of accident proneness. However, in this relatively young sample, there did not appear to be a relationship between the APQ and VAT. In future, the relationship between the APQ and VAT could be tested among older adults.

Keywords: dorsal stream, vision for action, accident proneness

The Relationship between the “Vision for Action” Pathway and Accident Vulnerability

There are many interacting components of the visual system that enable us to perform visually-guided actions. It is easy to take advantage of our ability to pick up an object from a cluttered table, but considering the processes underlying this action reveals how complicated it really is. We must identify the target object, manoeuvre our hand to avoid any obstacles on the table, configure the shape of our hand to the shape of the object, and anticipate the force required to lift it (Goodale, 2011). Our visual system is comprised of two processing pathways that enable us to undertake such tasks. The ventral stream helps us understand the composition of our visual environment, thus providing “vision for perception”. The dorsal stream processes spatial information and relationships, thus providing “vision for action” (Milner & Goodale, 2006). Frequently when people are involved in accidents, they might say “I did not see the car/curb/rock/step/door…” In reality, they probably saw the trigger of their accident, but did not pay attention to it (Lambert et al., 2018). Their accident was likely caused by a failure of their vision for action. The aim of this experiment is to determine whether variation in accident proneness can be explained by efficacy of dorsal stream vision for action. Accident proneness will be tested using the Accident Proneness Questionnaire (APQ; Lambert, Sharma, & Ryckman, 2019). Dorsal stream functioning will be tested using the Vision for Action Test (VAT; Lambert et al., 2019). Provided the APQ and VAT are reliable tests of accident proneness and vision for action, respectively, they offer potential in several movement-related applications. Relevant areas include identifying accident vulnerability in older adults, prevention of abnormal vision development, and driver screening (Lambert et al., 2019).

Two Distinct Pathways of Visual Processing

The distinction between the two functions of vision to identify information in the visual environment, and to enable successful movement through the environment has been an area of widespread research interest. The visual system is comprised of two pathways; the ventral stream network links the primary visual cortex (V1) with the inferotemporal cortex, and the dorsal stream network links V1 with the posterior parietal cortex (Milner & Goodale, 2006). Distinctions between these two pathways have been investigated in rhesus monkeys with lesions in either the ventral or dorsal stream (Mishkin, Ungerleider, & Macko, 1983). Monkeys with a lesion in their ventral stream could perform a visual landmark task, involving choosing a food-well close to a visual landmark, but performed poorly in perceptual discrimination. Conversely, monkeys with a lesion in their dorsal stream had perceptual discrimination as normal but were unable to complete the visual landmark task. Mishkin et al. (1983) proposed that the ventral stream could be considered the "what" pathway, responsible for encoding the identity of visual stimuli, and that the dorsal stream is the "where" pathway, specialised for encoding the location and spatial relationships of visual stimuli. This theoretical proposal of the two complementary pathways has been the basis of many other research studies and theories of dual-stream models of vision (e.g. Andersen & Buneo, 2003; Cohen & Andersen, 2002; Milner & Goodale, 2006; Tanaka, 2003).

A more current and widely accepted model of the visual streams is one proposed by Milner and Goodale (2006), which suggests the ventral stream pathway of visual processing is responsible for "vision for perception" while the dorsal pathway is responsible for "vision for action." Although similar to the model proposed by Mishkin et al. (1983), this model suggests that the dorsal and ventral streams encode both structural and spatial characteristics of the visual field, and it is the way information is transformed and used that differs between streams (Goodale, 2011). Vision for perception (in the ventral stream) uses visual information to create perceptual representations of the visual field and to understand their meaning. In contrast, vision for action (in the dorsal stream) uses visual information to determine spatial locations and relationships between stimuli, which then allows rapid control of visually-guided actions, such as reaching for an object (Milner & Goodale, 2006). Also, dorsal stream processing has been shown to occur independently of conscious awareness, while ventral stream processing has access to consciousness and working memory, using past experiences to inform current processing (Lambert et al., 2018). This shows that vision for action is out of our control; it is a more automatic process than vision for perception, which can use conscious decision making to selectively attend to relevant aspects of the visual field.

Unifying Vision and Attention

When reviewing the dual-stream model of vision proposed by Milner and Goodale (2006), several parallels can be drawn to two distinct attentional control mechanisms. Attentional control can be separated in terms of whether we consciously shift it or whether it is captured by external stimuli. Endogenous attention is under voluntary control, thus considered top-down because our brains are responsible for choosing what and where to focus. In contrast, exogenous attention is captured involuntarily, thus is bottom-up because salient changes in the environment cause shifts without intention (Chica, Bartolomeo, & Lupiáñez, 2013). The slower, voluntary nature of endogenous attention can be compared to conscious processing of visual information in the ventral stream, while the rapid, involuntary nature of exogenous attention can be compared to unconscious processing in the dorsal stream.

Lambert et al. (2018) made this connection and proposed that the dual-stream model of vision could be combined with the two mechanisms of attentional control into a unified model of vision and attention. This was tested by using two tasks of visual attention - a landmark task driven by encoding visual-spatial features of stimuli, and a discrimination task, involving processing the symbolic identity of stimuli. They found with longer exposures to visual cues, processing was driven by the symbolic identity of the cue (vision for perception) whereas when cue exposure was brief, visual-spatial features were more influential (vision for action). These differences can be explained by the different cellular properties of the two pathways. Fibres in the ventral stream predominantly originate from parvocellular (P-cell) layers of the lateral geniculate nucleus (LGN), as well as some from the magnocellular (M-cell) layers, whereas most fibres in the dorsal stream originate from magnocellular layers of the LGN (Livingstone & Hubel, 1988). P-cells exhibit a sustained response to visual stimuli and therefore produce stronger signals the longer a visual stimulus is on display. M-cells exhibit more transient responses, so are finely attuned to rapid changes in the visual field, even when stimuli are very brief (Lambert et al., 2018). These properties are also relevant to mechanisms of attention, as P-cell properties align with the slow, purposeful nature of endogenous attention, which is involved with semantic processing, just as the ventral pathway is. M-cell properties align with the fast, exogenous switches to transient stimuli, just as the dorsal stream is attuned to changes and movement in the visual field. The results of the study by Lambert et al. (2018) provide further support that visual processing can be separated into vision for perception and vision for action, and that this dual-stream model can be unified with endogenous and exogenous attention mechanisms.

Brain Imaging of the Ventral and Dorsal Streams

Research around visual pathways has also included several brain imaging studies. These contribute further evidence for the dual-stream hypothesis as they have revealed both patterns of spatial activation and time-course activation that are specific to each stream

(Goodale & Milner, 2018). Of interest is the use of electroencephalography (EEG) to determine the different patterns of activation between vision for perception and vision for action. Lambert and Wootton (2017) analysed the C1 and P1 components of visual event-related potentials and their source localisation, and compared these between a landmark task and a perceptual discrimination task. They found that the landmark task elicited a C1 component that was larger and occurred earlier in parietal-occipital sites. Such sites are located dorsally, suggesting early activation of the dorsal stream in response to visual-spatial landmarks in the visual field. In the perceptual discrimination task, there was widespread activation of the inferior temporal gyrus and fusiform gyrus during the early phase of the P1 component. The signals produced by these areas also increased at a later epoch. The inferior temporal gyrus and fusiform gyrus are components of the ventral stream, suggesting that the conscious discrimination required in the perceptual discrimination task takes longer to initiate but also involves a more sustained response from the ventral visual stream. Both the time-course activation and spatial patterns determined by EEG in this study support accounts of vision for perception and vision for action. Vision for perception takes longer to initiate and involves a sustained response, which is consistent with the concept of endogenous processing, whereas rapid activation of vision for action is key when responding to changes in the visual field.

When Damage Occurs

Due to the distinction between vision for perception and vision for action, and the spatial separation of these two pathways in the brain, damage to either pathway causes interesting and somewhat surprising outcomes on visual processing ability. One patient known as DF suffered a period of prolonged anoxia leading to bilateral damage to her ventral pathway. As a result, DF has severe visual agnosia, meaning she has immense difficulty recognising objects in her visual field (Marrett et al., 2011; Milner & Goodale, 2006). Despite this agnosia, her ability to perform visually-guided actions is not impaired (Marrett et al. 2011). In a perceptual discrimination task using letter cues, DF was adamant that she was unable to recognise the letters, and her attempts to determine the correct location of the target letter were comparable to chance. However, in a parallel task of landmark cues, she could correctly orient her attention in the direction cued by the same letters used in the discrimination task. While we have known about the two separate streams of vision for a long time, the results observed from DF's participation in the discrimination and landmark tasks illustrate the clear distinction between vision for perception and vision for action. They show that vision for action can still occur in the absence of vision for perception, and that surprisingly, with damage to the ventral stream one cannot assume that the entire visual pathway will be affected.

Applications: Visual Development, Healthy Ageing, and Driver Screening

With the growing body of evidence illustrating the distinct properties of dorsal and ventral streams of vision, research has also turned to what practical applications this evidence can provide, in areas from early visual development to how the streams affect accident vulnerability in older adults. Many visual abnormalities emerge in early childhood, some of which are associated with developmental disorders. Atkinson (2017) discussed how disorders such as Williams syndrome, hemiplegia, developmental dyslexia, fragile-X syndrome and likely autism all involve deficits in sensitivity to global motion, which is a process mediated by dorsal stream functioning. Atkinson characterised these deficits in sensitivity to global motion as "dorsal stream vulnerability" (DSV), which encompasses a group of problems including poor sensitivity to motion, difficulty integrating visual information and motor skills to plan actions, inattention, and poor number skills. Also, the dorsal stream is affected when there are structural abnormalities in the eyes themselves, in conditions such as amblyopia and strabismus. These conditions can lead to irregularities in the developing dorsal stream (Atkinson, 2017). Overall, DSV is far more prevalent than ventral stream vulnerabilities, not only in developmental disorders but in other genetic and acquired disorders. An understanding of how we can monitor dorsal stream functioning could inform research, and improve screening programmes that may prevent the development of dorsal stream abnormalities in later life.

In terms of visual processing and ageing, it is also the dorsal stream that is more vulnerable. Substantial deterioration in dorsal stream processing is evident early in the ageing process (Sciberras-Lim & Lambert, 2017). Recent research has suggested this is due to the different cellular inputs to the ventral and dorsal visual streams (Braddick, Atkinson, & Wattam-Bell, 2003). Cellular inputs to the dorsal stream originate primarily from m-cells, which are larger than p-cells, and neurons that are larger tend to be more vulnerable to cell degeneration. Also, there are far more p-cells than m-cells in the LGN, so m-cell degeneration is likely to produce more apparent changes in dorsal stream function than with an equal amount of p-cell degeneration in the ventral stream. Other evidence from MRI studies has revealed that age-related reductions in gray matter are more substantial in the dorsal stream than the ventral stream (Ziegler et al., 2012). Current interventions concerned with reducing the incidence of falls in older adults tend to focus on maintaining physical activity or regular assessment of visual acuity (Reed-Jones et al., 2013). However, as noted earlier, the involvement of vision in accidents goes beyond simple acuity. The dorsal visual stream is a potential target for interventions that may reduce falls in older adults.

Further applications of separating vision for action and vision for perception could be applied to driver screening for licensure. Currently, only a basic test of visual acuity involving discriminating a small string of letters is assessed to obtain a driver's licence in New Zealand. However, screening drivers using this test is not linked to better driving outcomes. Drivers with good visual acuity have the same risk of being involved in a collision as drivers with poor visual acuity (Ministry of Transport, 2016; Owsley & McGwin, 2010). Visual acuity alone does not reflect the complex tasks that are involved with driving. While visual acuity can be a useful measure for the ability to read road signs, further tests of contrast sensitivity, visual field assessment, processing speed, and attention assessments should be implemented in addition to visual acuity measures (Owsley & McGwin, 2010). In a study by Owsley and McGwin (2010), the Useful Field of View (UFOV) task was used to determine the ability of individuals to divide their attention between simultaneous targets in central and peripheral vision. They found older adults with impaired divided attention abilities were more likely to report driving difficulties. The UFOV or a similar task assessing efficacy of the dorsal visual stream could be implemented to better identify drivers at risk of collision. The relationship between dorsal stream functioning and driving has implications beyond research; it should inform policy to improve driver screening.

Finally, it should be noted that the assessment of dorsal stream vision for action could be implemented in other areas, such as a general assessment of coordination and sporting abilities. The capability of the dorsal visual stream to carry out spatial tasks is essential to many aspects of sport, such as intercepting a moving ball, quickly navigating towards a target location, and judging the timing of actions correctly (Gao et al., 2015; Miller & Clapp, 2011). Preliminary evidence has identified differences between the visuomotor ability of athletes and nonathletes (Gao et al., 2015). Such differences could be used to screen for athlete weaknesses and devise corresponding training programmes (Gao et al., 2015) or to identify those individuals who may have a natural affinity for sports (Miller & Clapp, 2011).

Handedness: Are lefties more accident-prone?

Another factor that could be linked to accident proneness is whether individuals predominantly use their left hand. Previous research has suggested that left-handers may be more accident-prone (Dutta & Mandal, 2006), involved in car accidents more frequently (Bhushan & Kahn, 2006), and may even die earlier than right-handers (Aggleton, Bland, Kentridge, & Neave, 1994; Coren & Halpern, 1991; Ellis & Engh, 2000). Potential explanations have posited that left-handers may struggle to adapt to a right-handed world (Mandal & Dutta, 2001), genetic or other acquired disorders may have an association with handedness (Coren & Halpern, 1991), or perhaps in countries that have historically sanctioned the use of the left hand, individuals with mixed-handedness or 'clumsy' handedness may be more accident-prone (Mandal, Suar, & Battacharya, 2001). While many studies have proposed a correlation between handedness and accident proneness, the degree and direction of such a correlation continues to be debated (Voyer & Voyer, 2015).

Handedness is typically measured using questionnaires that ask about an individual's degree of hand preference in a variety of tasks. Some have many items, for example, the 37-item Side Bias Questionnaire (Mandal, Pandey, Singh, & Asthana, 1992). However, a study comparing the 10-item Edinburgh Handedness Inventory (EHI) with a 4-item Short Form found that although brief, the 4-item form showed good model fit and was reliably correlated with scores on the 10-item inventory (Veale, 2014). Veale suggested that using the Short Form EHI reduces measurement error and misinterpretation of instructions. Therefore, in this study, the 4-item EHI will be used to investigate whether there is any correlation between handedness and accident proneness.

Building on the Findings of Lambert, Sharma, & Ryckman (2019)

Until recently, there had been no standardised test or measure specific to dorsal stream processing, only tests of visual processing as a whole (Lambert et al., 2019). A test of this nature would separate functions of spatial processing from those of object recognition and symbolic meaning so that the test measured vision for action independently from vision for perception. Lambert et al. (2019) designed the “Vision for Action Test” (VAT) to investigate the relationship between dorsal stream processing and accident vulnerability. The VAT is a correlate to dorsal stream functioning because it involves cues that indicate spatial information, of where a target cue will be. Participants are not required to determine any symbolic meaning of the cues, which would require the ventral stream. In addition to the VAT, Lambert et al. assessed accident vulnerability using a self-report questionnaire (the Accident Proneness Questionnaire [APQ]). The results indicated a strong correlation between the VAT and APQ, which was independent of age, visual acuity, and physical ability. This is promising initial evidence that accident vulnerability is related to vision for action, and that the VAT could be used to assess vision for action in applied settings. However, due to time constraints, the sample size in this study included only fourteen participants. While there was a moderate-to-strong correlation between VAT and APQ scores, the confidence interval for this correlation was wide. Therefore, it would be beneficial to test a larger sample and observe the resulting changes in statistical reliability.

This study is a near-replication of Lambert et al.’s (2019) study investigating the relationship between the VAT and participant self-reports of accident vulnerability. In Phase One, we aim to recruit a large sample of participants to complete the APQ, which will allow evaluation of its consistency and reliability. We will also be able to confirm whether accident proneness is independent of age, and whether there is any relationship between handedness and accident proneness. In Phase Two, we will test a subset of questionnaire respondents, particularly high- or low-scoring in the APQ, to determine whether APQ scores are related to VAT scores, and whether the relationship is independent of age. In accordance with the results of Lambert et al. (2019), we expect to observe a strong correlation between the VAT and APQ, that is independent of visual acuity and age. Also, we expect that the confidence interval of the correlation to be narrower than that observed by Lambert et al. (2019), because we will be testing a larger sample. The responsibility of processing spatial characteristics and relationships of visual information lies with dorsal stream vision for action (Milner & Goodale, 2006). Accidents involve misalignment of these abilities, causing us to bump into things or even crash our vehicles (Lambert et al., 2018). Therefore, we would expect an individual's tendency to be involved in accidents to be related to the capacity of their vision for action pathway in connecting what they see with what they do.

Method (Phase One)

Participants

554 adult volunteers responded to the online survey. The survey was distributed through the community advertising website *Neighbourly*, as well as the following universities: Auckland, Victoria, Waikato, Canterbury, Otago, Flinders (Adelaide), British Columbia (Vancouver), and Essex (UK). The participants were aged 17-87, with the majority aged 17-22. 410 females, 128 males, 7 gender non-conforming individuals and 9 others (who preferred not to respond) took part. All participants provided informed consent. This project was approved by the University of Auckland Human Participants Ethics Committee.

Design and Procedure

The survey included the Accident Proneness Questionnaire (APQ; Lambert et al., 2019), Edinburgh Handedness Inventory - Short Form (EHI; Veale, 2014), and demographic information (see Appendix). The APQ is a 13-item questionnaire that measures the self-reported level of accident proneness, encompassing the tendency to be clumsy or involved in falls, slips, trips, bumping into things, dropping things, or road accidents. The APQ items were statements such as “Do you trip over when walking, due to uneven ground, unseen obstacles, or misjudging the height of steps or stairs?” and “When turning at an intersection, do you sometimes fail to notice an approaching vehicle, and begin your turn when you should have waited?” Participants responded using a Likert scale with values ranging from 0 (never) to 4 (very often). The Short Form EHI (Veale, 2014) is a 4-item questionnaire that measures the preference to use one hand more than the other. The EHI asked participants to “Please indicate your preferences in the use of hands in the following activities or objects: Writing, Throwing, Toothbrush, Spoon.” Response options given were “always right”, “usually right”, “both equally”, “usually left”, and “always left”.

Method (Phase Two)

Participants

25 adult volunteers participated in Phase Two. These participants scored particularly high or low in the APQ during Phase One and were invited to Phase Two, which allowed us to disentangle the results from age and visual acuity. Majority of the participants were aged 18-34, with the addition of one 55-year-old and one 87-year-old. 13 females and 12 males took part. All participants provided informed consent. This project was approved by the University of Auckland Human Participants Ethics Committee.

Apparatus

The Freiburg Visual Acuity Test was conducted using a Dell Optiplex PC with a 23” LED monitor. Participants were seated 4m from the monitor and responded using a wireless keyboard. The Vision for Action Test (VAT) was conducted using an AOC AGON PC with a

25” LCD monitor and an Eyelink 1000+ eye tracker in a dimly lit, soundproof room. A chinrest was used to control viewing distance at 57cm. The experiment was observed from an adjacent room using two monitors, one for eye-tracking data and one for VAT responses.

Display and Stimuli

In the Freiburg Visual Acuity Test, Landolt C optotypes were presented at eight different orientations, in the centre of the screen. The contrast value was set at 100%. Pixel size was approximately 0.2mm and the size of optotype details (stroke width and gap width) subtended one-fifth of the overall optotype height. In the VAT, cue stimuli comprised a pair of bilateral shapes, a circle and triangle, presented on either side of a fixation cross. Each shape was approximately 1.3° (width) x 0.8° (height). The centre of each shape was presented 17° to the left or right of fixation. Target stimuli for this task were two different digits, either a “7” or “2” was presented on every trial, subtending 0.5° (width) x 0.7° (height). The target was presented 17° to the left or right of the screen centre.

Design and Procedure

In the Freiburg Visual Acuity Test, Landolt C optotypes were presented at varying sizes. Participants were asked to indicate the position of the gap in the optotype using the corresponding key on the number pad of the keyboard. Initially large (0.83°), the optotypes decreased in size until responses reached a guessing rate (12.5%). In cases where participants were unable to identify the position of the gap, they were asked to guess.

The VAT was based on the Landmark Cueing Procedure used by Lambert et al. (2018), carried out in two identical blocks. The procedure began with calibration of the eye tracker, then task instructions. Participants were informed that the target would appear on the same side as one of the shapes (triangles or circles, counterbalanced across participants). Their task was to identify the target as quickly as possible, using the up arrow to indicate a

"7", or the down arrow to indicate a "2". The first 10 trials were used for practice, and subsequently, the procedure continued until participants reached a response accuracy threshold of 75%.

Each trial began with the presentation of a central fixation cross; the cross appeared for 1000ms before a 100ms 'blink' (blank screen), after which it appeared again for 1000ms before another 100ms blink. The blinks were introduced to ensure participants were attending to the centre of the screen prior to each trial. Next, cue shapes appeared for 100ms followed by a variable stimulus onset asynchrony (SOA). The target digits appeared for 50ms and the screen remained blank until participants responded, or for 1000ms. The initial SOA value was 1000ms and was subsequently reduced via a staircase procedure (Findlay, 1978) until participants reached the 75% accuracy threshold. If participants did not exceed 75% accuracy with an SOA of 1000ms, their threshold was recorded as 1000ms. Trials were recorded as correct if participants discriminated the target correctly, or if they launched a saccade of 4° or more in the direction of the landmark shape. Trials ended with a 1250ms inter-trial interval.

Results (Phase One)

An item analysis was conducted to evaluate the internal consistency of the APQ items. Question six had an insignificant and small negative correlation with overall APQ score (r = -.6, p = .156) thus was excluded. In addition, question eight had an insignificant and small positive correlation with overall APQ score (r = .22, p < .001). This is below the minimum correlation recommended by Kline (2000) of r = .3, thus was also excluded. With the 11-item version of the APQ, the value for Cronbach's alpha was 0.72. Cronbach's alpha is a measure of internal consistency, describing how much the items of a questionnaire are correlated with the other items (Cronbach, 1951). It is expressed as a value between zero and one, with a higher value denoting greater reliability. Generally, Cronbach's alpha values that are between 0.7 and 0.8 are considered satisfactory (Tavakol & Dennick, 2011).

While question 12(a) also had a small, positive correlation that was less than the recommended value ($r = .25$, $p < .001$), the 11-item APQ still achieved a Cronbach's alpha value greater than 0.7. There are good theoretical grounds to retain question 12 as it asks directly about road accidents. It is likely that the correlation was small because road accidents are comparatively rarer than trips and slips. Further, removing question 12 had little effect on Cronbach's alpha ($\alpha = 0.74$). The mean inter-item correlation (another measure of internal consistency) for the 11-item APQ was 0.19. This falls within the range recommended by Clark and Watson (2016) of 0.15 to 0.5.

There was no reliable relationship between handedness and APQ score ($r = .01$, $p = .76$). However, there was a small but significant negative correlation between handedness and age ($r = -.10$, $p = .02$). Although weak, this suggests that older people may be less likely to be left-handed. Finally, there was a small but significant negative correlation between age and accident proneness ($r = -.17$, $p < .001$). This suggests that younger participants have somewhat higher APQ scores. Table 1 shows the correlations between APQ items and overall 11-item APQ score.

Table 1

Correlation Between APQ Items and 11-Item APQ Score

	Pearson Correlation	Sig. (2-tailed)	N
1	.567	< .001	554
2	.462	< .001	553
3	.694	< .001	554
4	.476	< .001	554
5	.634	< .001	554
7	.616	< .001	554
8	.380	< .001	554
10	.376	< .001	412
11	.383	< .001	412
12	.253	< .001	451
13	.694	< .001	550
Age	-.167	< .001	523
Handedness	.013	.761	554

Results (Phase Two)

The primary analysis of Phase Two was the partial correlation between APQ scores and VAT scores, controlling for age and visual acuity. Unlike the central hypothesis (that there would be a strong correlation between APQ scores and VAT scores), the correlation was statistically insignificant, small, and negative (r = -.12, df = 20, p = .604, two-tailed).

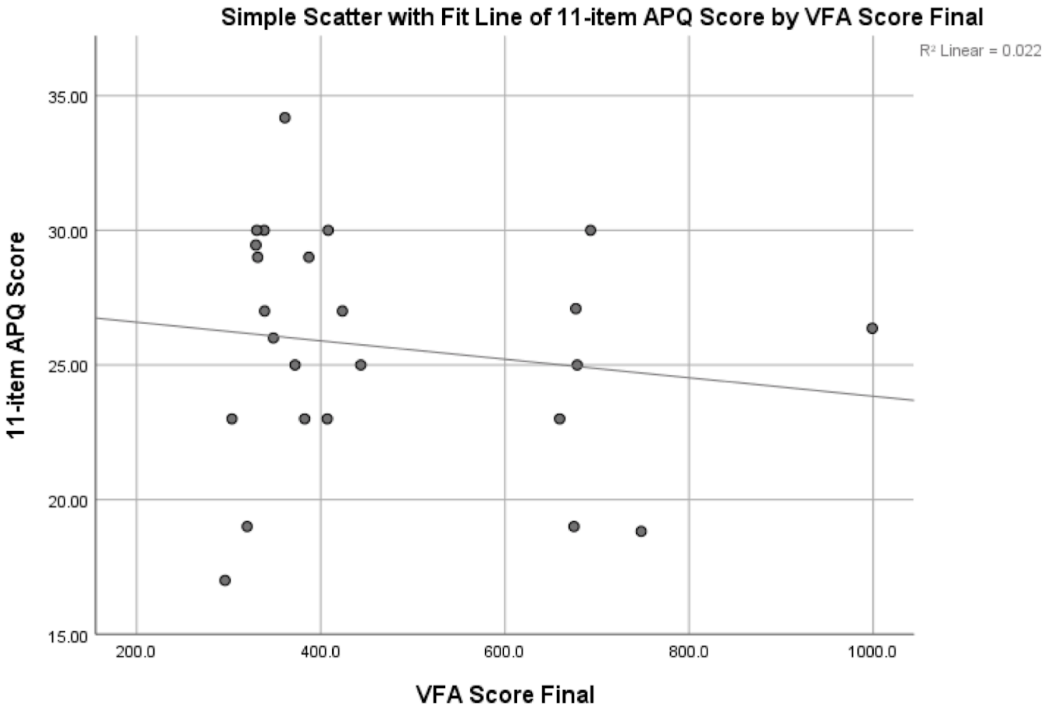

Figure 1. A scatter plot illustrating the insignificant relationship between 11-item APQ scores (accident vulnerability) and VAT scores (vision for action), controlling for age and visual acuity.

Post-hoc exploratory analyses were conducted to investigate whether there was any relationship between eye saccades and APQ scores. These are shown in Table 2. The correlations between APQ score and saccade reaction time, and between APQ score and saccade accuracy both failed to reach significance. There was a significant, large, and negative correlation between age and saccade accuracy, but upon closer inspection it was realised this correlation was driven solely by the 87-year-old participant ($r = -.84$, $p < .001$). The relationship between age and saccade reaction time also failed to reach significance. There was no practise effect between the first and second VAT trials.

Table 2

Correlation of 11-Item APQ Score with VAT Score, Age, Acuity, and Eye Saccades

	VAT Score	Acuity Score (dec. VA)	Age	Saccade Reaction Time	Saccade Accuracy
Pearson Correlation	.307	-.149	.252	-.091	.224
Sig. (2-tailed)	.488	.235	.178	.710	.357
N	24	24	24	19	19

Discussion

This study was a near-replication of Lambert et al.'s (2019) study, aiming to determine whether there is a relationship between accident proneness, measured using the APQ, and vision for action performance, measured using the VAT. We sought to determine whether the APQ is a reliable and consistent measure of accident proneness, and whether there is a relationship between accident proneness and age, or a moderating effect of age on the relationship between VAT scores and APQ scores. In accordance with Lambert et al.'s (2019) study, we expected to find a strong correlation between the VAT and APQ, that was independent of visual acuity and age. Unexpectedly, we found no reliable relationship between APQ sores and VAT scores in this sample. There are several possible reasons we did not find a reliable correlation. We suspect that it was due to the relatively young ages of the participants in our sample (18-34). While Lambert et al. (2019) found the relationship between the APQ and VAT to be independent of age and visual acuity, age may have a moderating effect more complex than independence. It could be that the relationship between vision for action and accident proneness grows stronger with age, or that individuals are adept at avoiding accidents in their youth, independently of their vision for action proficiency. Despite the lack of relationship between the APQ and VAT, we did find the APQ to be a reliable and consistent questionnaire across 11 items.

The Accident Proneness Questionnaire

Before the APQ was developed, there was no conventional measure of accident proneness (Lambert et al., 2019). The APQ is designed to measure a person’s tendency to be involved in falls, slips, trips, bumping into things, dropping things, or road accidents. It was designed with visual pathways in mind, specifically that it might be related to a person’s ability to use their dorsal visual stream competently. There are several questionnaires and scales designed to measure concepts like accident proneness, but include non-visual accidents or are designed for a specific setting. As early as 1940, Cobb recognised the need for a method to estimate accident proneness other than observation of accident rate. He highlighted the limitations of using accident rate to measure accident proneness, such as that accidents vary in severity, thus can be difficult to compare. While similar concepts are tested in clinical and industrial settings, none are targeted at the vision for action pathway.

Measures of Coordination, Accidents, and Cognitive Failures. The Adolescents and Adults Coordination Questionnaire (AAC-Q; Saban, Ornoy, Grotto, & Parush, 2012) was designed to identify Developmental Coordination Disorder (DCD) among adults, as previously only a questionnaire targeted at children existed. The AAC-Q includes items such as “I tend to be clumsy, fall often, drop items, or bump into objects” and “I have difficulties with physical activities”, which participants are asked to rank on a Likert scale. As designed for a clinical population, the AAC-Q also includes items that are specific to DCD and would be irrelevant for the general population. However, elements of the AAC-Q are similar to the

APQ, and provide good theoretical grounds that such questions reliably measure characteristics of accident proneness.

There have been a few versions of accident proneness questionnaires specific to an occupational setting. These differ from the APQ we used as they are specific to certain contexts and industries. The Accident-Proneness Scale developed by As (2001) asked employees in the chemical industry about their involvement in any accidents at work, whether they had witnessed any, and whether they had experienced any near-misses. Simply asking employees about the number of accidents they have been involved in is insufficient; this number can be highly coincidental. Therefore, most APQ-items phrase questions in terms of how concerned an individual is about being involved in an accident, rather than if they were involved in one. The accident proneness questionnaire designed by Gauchard et al. (2006) asked railway workers how many occupational injuries they had been involved in during the previous three years. However, their questionnaire was concerned with potential determinants of accident proneness such as sleep disorders, smoking, and lack of physical activity. The studies by As (2001) and Gauchard et al. (2006) each designed a version of an accident proneness questionnaire. However, neither are concerned with the relationship between accidents and brain pathways, or the dorsal visual stream.

Another questionnaire related to accidents, specific to driving accidents, is the Everyday Behaviours Questionnaire (EBQ; Nakagawa, Park, & Kumagai, 2013). This questionnaire is completed by family members of an elderly driver, and alongside driving frequency was shown to be significantly predictive of crash involvement. EBQ items include “He/she misses or nearly misses a step on the stairs more frequently than he/she used to,” which respondents are asked to rate on a Likert scale. Although the EBQ does not include any items related to driving, it still successfully predicts crash involvement within the three years prior to the survey being filled out. These results show that accident proneness is highly relevant to not only everyday accidents, but vehicle accidents as well. Although subjective, the EBQ remains a successful measure.

In a slightly different vein, the Cognitive Failures Questionnaire (CFQ; Broadbent, Cooper, FitzGerald, & Parkes, 1982) measures self-reported failures in perception, memory, and motor function. The CFQ measures accidents of a sort - accidents of the mind, which includes failures in vision for action. The CFQ has been widely used since its inception and is reliable across time, more so than other measures (Bridger, Johnsen, & Brasher, 2013). It is frequently used as a correlate of accident proneness and psychological strain (Day, Brasher, & Bridger, 2012). Some CFQ items relate to the APQ, such as “Do you bump into people?” and “Do you drop things?” Other items include “Do you find you forget whether you’ve turned off a light?” and “Do you find you accidentally throw away the thing you want and keep what you meant to throw away?” To create a questionnaire specific to accident proneness in an everyday setting, a phenomenon relevant to all individuals, the APQ items were designed to measure common accidents attributable to vision, not unlike the CFQ. The APQ can be compared to the AAC-Q, CFQ, and occupational-accident proneness questionnaires, but ultimately is specific to movement-related mistakes in everyday life. This allows the use of the APQ to investigate errors in visual motion processing, which is mediated by the dorsal visual stream.

Internal Validity of the APQ. As suggested by Clark and Watson (2016), an important part of test construction is to start with more items than necessary, then eliminate some items to find those that most accurately describe the concept in question. We started with 13 APQ items, all asking about a variety of everyday accidents (slips, trips, and collisions). The next step was to determine whether the items were significantly correlated to each other, thus giving a high internal consistency. We eliminated two items, asking whether respondents had ever required medical attention for an accident, and whether respondents had been involved in any accidents as a pedestrian. This gave a satisfactory value of Cronbach's alpha. In addition, eliminating unnecessary items from the APQ decreased the risk that a large Cronbach's alpha is due to a high number of items, rather than actual internal consistency (Clark & Watson, 2016). While the satisfactory values of inter-item reliability and Cronbach's alpha suggest that the APQ has high internal consistency, other considerations should be made to determine whether the scale is sufficiently homogenous and unidimensional. This can be determined by considering whether inter-item correlations are similar and fall within a narrow range. As shown in Table 1, all inter-item correlations are clustered within 0.25 and 0.64 (excluding age and handedness). Not only is this successful because the similar values suggest unidimensionality, but also because all are moderate correlations. This ensures that no two items are measuring the same thing, thus no items are redundant, and the inter-item correlation remains a valuable measure (Clark & Watson, 2016).

Handedness. While APQ scores were independent of handedness and age, there was a small but significant negative correlation between left-handedness and age. In such a large sample, this suggests that older participants may be less likely to be left-handed. It is possible that this reflects a cultural shift away from the suppression of left-handedness. As late as the mid-twentieth century, children were discouraged against left-handed behaviour (Annett, 1976). However, a study by Coren (1994) found that age-related declines in left-handedness persisted despite recruiting a sample that was unaffected by cultural pressures against left-handedness. Coren suggested that the negative correlation between left-handedness and age is due to a higher risk of early mortality for left-handers. Our results lacked a reliable relationship between accident proneness and handedness. One might predict that for left-handers to have a higher risk of early mortality, they might also have a higher risk of being involved in accidents. Our results were inconsistent with this explanation, leaving room for further investigation. Perhaps a future study could use public health data to determine whether left-handers have an average age-of-death that is younger than the average of right-handers, and whether there are more accident-related deaths among left-handers.

The Vision for Action Test

In contrast to the correlation found by Lambert, Sharma, and Ryckman (2019), we did not find a reliable correlation between APQ scores and VAT scores. One interpretation might be that the results found by Lambert et al. were spurious. However, it is likely that age has a more complex moderating effect on the relationship between accident proneness and vision for action than predicted. Our sample varied greatly from that of Lambert et al. as there were only two participants in Phase 2 aged 35 or older. In their earlier sample, there was a more even split, with nine participants younger than 30 and eight older than 65. While APQ and VAT scores were independent of age, it could be that the relationship between accident proneness and vision for action grows stronger with age. That is, younger individuals are adept at using their vision for action effectively and avoiding accidents. When these skills begin to deteriorate could be when the relationship between APQ and VAT scores emerges.

When re-examining the results found by Lambert et al. (2019) it appears the correlation between APQ and VAT scores was largely driven by the older participants. Among younger participants, it is likely that factors other than accident proneness influence the actual number of accidents participants are involved in. For example, more than half of at-fault drivers who are classified as high-risk in New Zealand are under 30 (Ministry of Transport, 2012). It is a well-known fact that younger individuals engage in riskier behaviours than older individuals (Graham, Jordan, Hutchinson, & Wet, 2018). Therefore, APQ scores of younger participants may not be completely indicative of accident proneness. Another possible difference between our data and lived experience is that younger people may be better at avoiding accidents despite their accident proneness. For example, they might be more skilled at recovering from a small trip without falling over. As individuals age, it may become harder to avoid more drastic negative outcomes of accidents, due to physical limitations. While accident proneness may remain a stable trait across the lifetime, what does change with age is how well our bodies can adapt to sudden visual changes (Moenter, Glen, & Crabb, 2014). Therefore, while the relationship between APQ scores and VAT scores may be independent of age, perhaps the outcomes of a person's accident proneness become more obvious with age.

Future Directions

The main limitation of this study was that few older participants were recruited. If the relationship between APQ scores and VAT scores is, in fact, stronger with age, it is no surprise that we did not find a reliable correlation between the APQ and VAT with only two participants older than 35. In future, it would be useful to not only recruit a larger sample, but to also focus on recruiting a substantial number of participants aged 65 or more. While a sample of 554 people completed the APQ in this study, only 150 of those participants indicated any interest in participating in phase two. Of those, only the final 25 participants arranged a time to participate. Given more time, it would likely have been possible to organise more of the APQ respondents to participate in phase two. In addition, the APQ was mostly advertised in a university setting, and the clear majority of student populations are younger than 30. It would have been beneficial to advertise the APQ through other avenues, such as in retirement villages or perhaps among community groups of retired individuals.

If our hypotheses had been met, the VAT would have been a promising method of measuring accident vulnerability that eliminated the self-report required for the APQ. The main limitation of the APQ is that it relies on respondents to remember any accidents they were involved in retrospectively, and asks for a purely subjective level of clumsiness. It is difficult to have a baseline that individuals can compare themselves to, because no person is completely non-accident prone. The vision for action pathway is likely involved in most accidents, thus measuring the effectiveness of the dorsal visual stream would indicate an individual's vulnerability to be involved in accidents. If our hypotheses had been correct, the VAT would have shown to be a good measure of accident proneness, which would have suggested a strong relationship between vision for action and accidents. If this relationship is investigated further, the plausibility of using the VAT as an objective measure of accident vulnerability should be explored.

In a situation where more participants were recruited and there still failed to be a reliable relationship between the APQ and VAT, there are other ways to reduce any variation due to self-report. For example, to reduce any error arising from the retrospective nature of the APQ, a diary study could be designed that asked participants to report at the end of each day whether they were concerned about or involved in any accidents during that day. This would make it easier for participants to remember, thus making their responses more accurate. Otherwise, the CFQ (Broadbent et al., 1982) has remained a reliable measure of cognitive failures since its inception not only because of its internal consistency and homogeneity, but also because it is frequently used alongside a “CFQ for others”. This is a questionnaire like the CFQ but is filled out by someone close to the participant in question. It asks questions such as “During the last six months, has your relative or partner seemed to be clumsy, for example, dropping things or bumping into people?” The CFQ for others supplements the CFQ with an evaluation that is less likely to influenced by an individual's beliefs about their own cognitive failures, which may not be aligned with their true selves. A similar aspect of the APQ could be developed - the 'APQ for others'. Partners or relatives of a subject could be asked to fill out the APQ for others, not only to eliminate self-report bias, but also to identify any differences between one's own beliefs about their accident proneness and their true tendency to be involved in accidents.

Conclusion

The dorsal visual stream plays a crucial role in successfully navigating us through our spatial environment, providing vision for action (Milner & Goodale, 2006). When dorsal stream performance is less than optimal, we are more vulnerable to accidents and collisions, clumsiness, and injuries (Lambert et al., 2018). Accident proneness was measured using the APQ, and vision for action performance was measured using the VAT. Although we did not find a reliable correlation between the APQ and VAT, it is possible that such a relationship might emerge in a larger sample of older participants. Perhaps the relationship between vision for action and accident proneness emerges with age, because individuals are adept at avoiding accidents in their youth, independently of their vision for action proficiency. If not, we have still found the APQ to be reliable, with moderate inter-item correlations and high internal consistency. In future, the APQ could be a valuable asset in the detection of older adults who are at risk of falling and injury.

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Appendix A

Accident Proneness Questionnaire

1. Have you had a fall in the last year?

   No (1)

   Yes (2)

2. When walking across a slippery surface, such as a wet floor or muddy pavement/sidewalk, how concerned are you about slipping over?

   Not at all concerned (1)

   Slightly concerned (2)

   Somewhat concerned (3)

   Fairly concerned (4)

   Very concerned (5)

3. Do you trip over when walking, due to uneven ground, unseen obstacles, or misjudging the height of steps or stairs?

   Never (1)

   Very rarely (2)

   Occasionally (3)

   Quite often (4)

   Very often (5)

4. Have you ever required medical attention, as a result of having a fall?

   No (1)

   Yes (2)

5. Do you hurt yourself as a result of bumping into objects such as furniture, doors or lamp posts?

Never (1)

Very rarely (2)

Occasionally (3)

Quite often (4)

Very often (5)

6. Have you ever required medical attention as a result of bumping into objects such as furniture, doors or lamp posts?

Yes (1)

No (2)

7. Do you drop things you are holding such as your phone, cups or books?

Never (1)

Very rarely (2)

Occasionally (3)

Quite often (4)

Very often (5)

8. Within the past 5 years have you been involved in a road accident as a pedestrian?

Never (1)

Once (2)

Two times (3)

Three times (4)

Four or more times (5)

9. When crossing the road (as a pedestrian), do you sometimes fail to notice an approaching vehicle and begin to cross, when you should have waited?

Never (1)

Very rarely (2)

Occasionally (3)

Quite often (4)

Very often (5)

10. Do you drive OR ride a motorbike OR cycle on the roads?

Yes (1)

No, I do not drive, or ride a motorbike, or cycle on the roads (2)

10. a. Do you sometimes fail to notice someone crossing at a pedestrian crossing, and keep driving/riding/cycling when you should have stopped?

Never (1)

Very rarely (2)

Occasionally (3)

Quite often (4)

Very often (5)

11. When turning at an intersection, do you sometimes fail to notice an approaching vehicle, and begin your turn when you should have waited?

Never (1)

Very rarely (2)

Occasionally (3)

Quite often (4)

Very often (5)

12. What is your primary method of road transport?

Driving (1)

Riding a motorbike or scooter (2)

Cycling (3)

None of the above (4)

12. a. Within the past 5 years have you been involved in a road accident while driving?

Never (1)

Once (2)

Two times (3)

Three times (4)

Four or more times (5)

12. b. Within the past 5 years have you been involved in a road accident while riding a motorbike or scooter?

Never (1)

Once (2)

Twice (3)

Three times (4)

Four or more times (5)

12. c. Within the past 5 years have you been involved in a road accident while riding a bicycle?

Never (1)

Once (2)

Twice (3)

Three times (4)

Four or more times (5)

13. How clumsy are you?

1 - not at all clumsy (1)

2 (2)

3 (3)

4 (4)

5 - very clumsy (5)

14. Please indicate your preferences in the use of hands in the following activities or objects:

	Always right	Usually right	Both equally	Usually left	Always left
	(1)	(2)	(3)	(4)	(5)
Writing (1)					
Throwing (2)					
Toothbrush (3)					
Spoon (4)					