The Dance of Light and Motion: A Comprehensive Review of the fenomenal Stroboscopic and marvelous Wagon Wheel Effects. Mechanisms, Applications, and Challenges

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Abstract

In the enthralling world where light and motion converge, the stroboscopic effect and the wagon wheel effect stand out as captivating phenomena that continue to perplex and inspire. This review article provides a comprehensive examination of the stroboscopic effect and the wagon wheel effect, two intriguing optical phenomena that have garnered significant attention in both scientific and practical contexts. We delve into the underlying mechanisms, historical perspectives, diverse applications, and challenges associated with these effects, employing a scientific lens to elucidate the complexities involved. The stroboscopic effect and the wagon wheel effect are both optical phenomena related to motion and visual perception, but they arise from different mechanisms and have distinct characteristics.

Keywords: the stroboscopic effect, optical illusion, wagon wheel effect, information technologies, high-speed imaging, motion analysis.

DOI: 10.7176/APTA/88-03
Publication date: March 28th 2024

1. Introduction

The study of visual phenomena has long been a captivating pursuit, delving into the intricacies of human perception and the fascinating interplay between motion and vision. Two phenomena that stand at the intersection of these realms are the wagon wheel effect and the stroboscopic effect. The wagon wheel effect, an unintended consequence born from the marriage of rotating wheels and modern imaging technologies, has piqued the curiosity of scientists and researchers alike. This intriguing phenomenon introduces perceptual distortions, offering a unique lens through which to examine the intricate relationship between visual perception and the constraints of imaging systems. As we navigate through the complexities of the wagon wheel effect, we unveil a phenomenon with both theoretical significance and practical implications, influencing fields as diverse as cinematography, robotics, and digital image processing. In parallel, the stroboscopic effect beckons our attention—a deliberate manipulation of light and motion that relies on the persistence of vision. Frequently employed intentionally, the stroboscopic effect has left an indelible mark on diverse domains, from artistic performances to scientific experimentation. Understanding the deliberate orchestration of this visual phenomenon involves delving into the mechanics of human vision and the intentional modulation of light pulses to create illusions of motion.

2.Unveiling the Stroboscopic Effect: A Dance of Light and Perception

In the realm of visual perception, the stroboscopic effect stands out as a captivating phenomenon that mesmerizes both scientists and artists alike. This optical illusion, born from the interplay of light and motion, creates a surreal dance that challenges our understanding of reality. Let's look at some aspects to unlock the secrets behind the stroboscopic effect.

The stroboscopic effect occurs when a series of still images, presented at a rapid pace, create the illusion of continuous motion. This effect relies on the persistence of vision, a fascinating trait of the human eye that retains an image for a brief moment after its disappearance. By exploiting this phenomenon, scientists and artists have discovered a myriad of applications for the stroboscopic effect.

2.1 Mechanisms Governing Persistence of Vision

Expounding upon the neurological and physiological aspects of persistence of vision, we elucidate how the stroboscopic effect capitalizes on the brain's ability to integrate successive visual stimuli, resulting in the perception of continuous motion (Sekulovski and Poort 2020).

2.2 The Science Behind the Illusion

At its core, the stroboscopic effect capitalizes on the brain's ability to blend successive images into a seamless motion. When individual frames are displayed at a high frequency, the brain perceives them as a fluid and continuous movement. This principle is fundamental to various technologies, from early animation devices to contemporary cinema and even applications in scientific research (Perz & Vogels 2015).

2.3 Historical Significance

The term "stroboscopic effect" is closely associated with the field of optics and the perception of motion. While it's challenging to pinpoint a single individual who first coined the term, its usage became more prominent with the development of technologies and experiments related to visual perception and motion studies. The roots of the stroboscopic effect can be traced back to the early experiments of pioneers like Eadweard Muybridge, who employed a series of still photographs to analyze the gaits of animals in motion (Versluis 2013). These groundbreaking studies paved the way for the development of motion pictures and fundamentally altered the way we capture and understand movement. Muybridge conducted extensive motion studies using a series of still photographs to capture and analyze the gaits of animals and humans. While Muybridge may not have explicitly used the term "stroboscopic effect," his experiments and contributions to the understanding of motion were instrumental in the eventual recognition and exploration of this visual phenomenon.

This effect was first observed and documented by Peter Mark Roget, an English physician and natural theologian, in the early 19th century (Thomas & Greenslade 1992). Roget's observations laid the foundation for the development of stroboscopy, which is a technique that uses a strobe light to make fast, periodic motion sequences appear in slow motion or even stationary. This method has found applications in various fields, including physics, biology, and entertainment.

Terminologically, it was first used in 1833 by Simon Stampfer. Stampfer, an Austrian physicist, used a rotating disc with radial slits to create the stroboscopic effect and named the device a "stroboscope" (Stampfer & Blower 2016). This term has since been widely adopted to describe the phenomenon and the related apparatus used to produce it.

2.4 Modern Applications

In the digital age, the stroboscopic effect continues to shape our encounters with technology. High-speed photography and video techniques leverage this phenomenon to capture split-second moments, offering insights into realms invisible to the naked eye. Moreover, entertainment industries deploy stroboscopic lighting effects to create unforgettable visual spectacles in concerts, clubs, and live performances (Perz & Sekulovski 2018). By exploiting this phenomenon, scientists and artists have discovered a myriad of applications for the stroboscopic effect. Let's consider some specific applications of the stroboscopic effect:

1) Motion Analysis in Sports and Biomechanics:

Scientists use stroboscopic photography to analyze the movements of athletes. By capturing rapid sequences of still images, researchers can break down complex motions like a golf swing or a gymnastic routine. This application has contributed significantly to the enhancement of athletic performance and injury prevention (Kelly 1961).

2) Automotive Engineering and Safety Testing:

Stroboscopic lights are employed in crash testing and automotive engineering. Rapidly flashing lights synchronize with high-speed cameras to capture precise moments during impact tests. This aids in understanding the dynamics of collisions and contributes to the development of safer vehicles (Piscataway 2015).

3) High-Speed Photography:

Stroboscopic flashes play a crucial role in high-speed photography, freezing fast-moving subjects in a series of distinct moments. This is valuable for capturing events such as the bursting of balloons, the splashing of droplets from an object falling into a liquid, or the trajectory of a speeding bullet and ect.

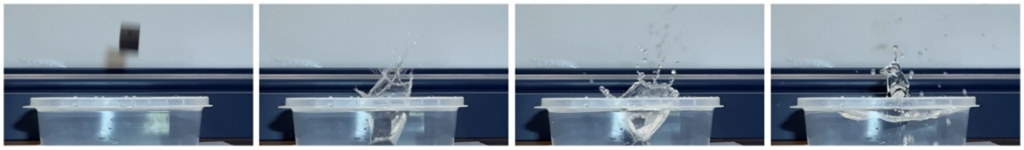

Figure 1. A visual representation of fast-moving processes in extremely slow motion

4) Artificial Illumination in Entertainment:

Stroboscopic lighting effects are widely used in the entertainment industry, especially in concerts, clubs, and live performances. The rhythmic pulsing of lights creates dynamic visual spectacles that synchronize with the beat of music, enhancing the overall experience for the audience (Perz & Sekulovski 2017).

5) Scientific Research and Experimentation:

In scientific laboratories, stroboscopic techniques are employed to study rapid processes that are otherwise imperceptible to the human eye. This includes experiments in physics, chemistry, and biology where precise timing and observation of fast events are essential.

6) Stroboscopic Animation and Film:

The stroboscopic effect has been a foundational principle in animation and filmmaking. Early animation devices, such as the zoetrope, relied on a stroboscopic-like mechanism to create the illusion of motion. Today, this principle continues to influence animation techniques and special effects in cinema.

7) Psychological and Perception Studies:

Researchers utilize stroboscopic stimuli to investigate visual perception and cognitive processes. By manipulating the timing and frequency of flashes, scientists can explore how the brain interprets and processes visual information, providing insights into human perception (Hogben & Lollo 1985).

8)Art Installations and Exhibitions:

Contemporary artists often incorporate stroboscopic effects into their installations and exhibitions. These dynamic light displays create immersive environments, challenging viewers to engage with art in novel and thought-provoking ways (Frier & Henderson 1973). These applications showcase the versatility of the stroboscopic effect, extending its reach across various fields, from scientific research to artistic expression and practical engineering. While the stroboscopic effect opens new frontiers in artistic expression and scientific discovery, it also poses challenges. Issues related to health, such as photosensitive epilepsy triggered by rapid light changes, underscore the need for responsible use and regulation of stroboscopic Technologies (Porciatti & Bonanni 2000).

3. The Enigmatic Wagon Wheel Effect: Unraveling the Mysteries of Spinning Wheels

The Wagon Wheel Effect is a type of strobe effect. In the realm of optical illusions, the wagon wheel effect stands out as a curious phenomenon that perplexes and captivates observers. Picture this: a spinning wagon wheel appears to defy the laws of physics, seemingly changing direction or even coming to a halt (Purves 1996).

3.1 Understanding the Basics

The wagon wheel effect, occurs when a spoked wheel appears to rotate in a direction different from its actual motion. This optical illusion arises from the interaction between the speed of the wheel's rotation and the frame rate of the capturing device, such as a camera or the human eye (VanRullen & Koch 2003). The result is a mesmerizing display that challenges our understanding of visual Dynamics (Pakarian & Yasamy 2003).

3.2 How It Works

The wagon wheel effect is intricately tied to the concept of aliasing, where a sampled signal (in this case, a rotating wheel) is incorrectly reconstructed. When the wheel's rotational speed aligns with the frame rate of the capturing device, aliasing creates the illusion of a reversed or stationary rotation. This phenomenon often occurs in video recordings, films, or even when observing wagon wheels in motion under artificial lighting.

Objects moving in real time transform into different visual states within a certain time and speed, creating an illusion effect (Andrews & Coppola 1999). This phenomenon, observed both during the rotation of the wheels and during the rotation of the helicopter wings, has attracted the interest of many researchers. Depending on the prism of the approach, the event is being explained in different directions. The rapid changes that the human eye can see are limited in our perception (Bullough & Marcus 2016). Research shows that humans can detect changes in visual stimuli incredibly quickly, with estimates ranging from about 200 to 500 milliseconds for detecting brief visual stimuli. This fast processing allows us to perceive motion, changes, and fast-moving objects without seeing them as a series of distinct frames (Borghuis & Tadin 2019). To observe this effect, the following factors should be taken into account:

1) Physiological factors. This includes physiological factors such as human eye fatigue, visual acuity, age factor.

2) speed of movement of a moving object

3) Illumination level of the light source

4) Time modulated light waveform (eg sine wave, square wave and its duty cycle) (Perz 2019; Perz & Sekulovski 2018).
As the wheel rotates, the simulation model observes 3 main and several additional transitions that can be seen by the eye. Here are the main links (Andrews & Purves 2015).

1. Movement in the direction of movement

2. Stop effect

3. Movement in the opposite direction of movement

During additional transitions, a diffuse visual image is observed. We can see this visually in fig.2

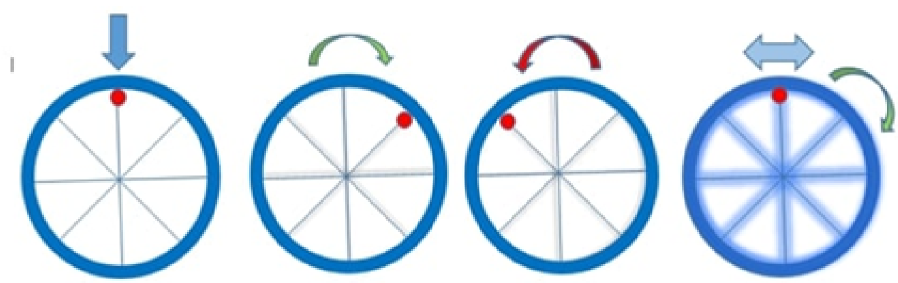

Figure 2. Wagon wheel example.

Differences in the direction of movement can be observed in different lines depending on the distance from the center on the same object. It should also be noted that the wagon wheel effect is sometimes dangerous. Thus, the worker may visually think that a moving object, such as a circular saw, is stationary. However, the circular saw is actually in motion, and due to the wagon wheel effect, it appears stationary because the frequencies of motion overlap. Or the worker may perceive it as moving backwards. This kind of illusion can lead to tragedy by mistake.

3.3 Real-Life Examples

1) Movies and Television:

The wagon wheel effect has made its mark in the entertainment industry. Filmmakers and television producers sometimes encounter this phenomenon, especially when capturing fast-moving scenes involving wheels. Directors must carefully consider camera settings to avoid unintended visual distortions (Purves & Paydarfar 1996).

2) Traffic Surveillance Cameras

Surveillance cameras monitoring busy roadways may inadvertently capture the wagon wheel effect, particularly when recording vehicles with spoked wheels. Understanding and mitigating this effect is crucial for accurate traffic analysis and surveillance.

3) Historical Photography

The wagon wheel effect is not exclusive to modern technology. In historical photographs, where exposure times were longer, fast-spinning wheels could create ghostly or distorted images, offering unintentional glimpses into the challenges photographers faced in capturing dynamic scenes.

3.4 Explanation of the wagon wheel effect by simulation method

Understanding the wagon wheel effect is essential for those working with cameras and recording devices. To minimize or eliminate this phenomenon, various strategies can be employed, including adjusting the shutter speed, modifying the frame rate, or utilizing anti-aliasing techniques in digital imaging (Pakarian & Yasamy 2003). Movie cameras traditionally shoot at 24 frames per second. If any object makes 24 revolutions per second, that object appears as if it is not moving. If the object hits 23 cycles, it creates an impression as if it has gone backwards. If it cycles 25 times, it seems to have moved forward. By adding patterns to the rotating bodies, the same results can be obtained by reducing the number of rotations (Van Rullen 2006). Let's take a look at the following pictures to understand this better. In fact, each gear shot in any given position will have a different real talk in each successive frame, but the shape and color of the studs are so similar that the difference is imperceptible.

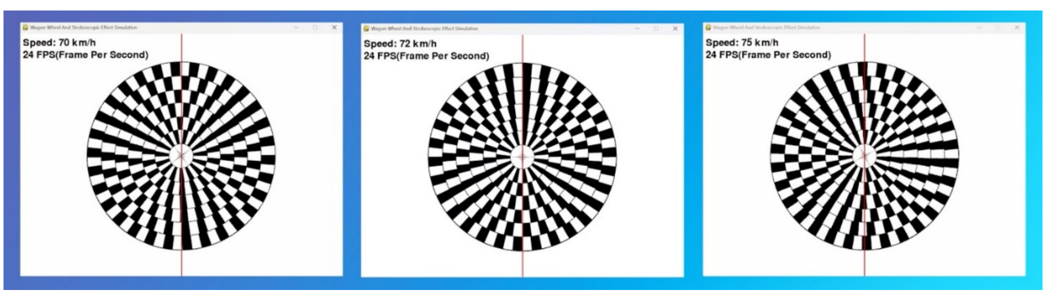

Figure 3. Simulation of wagon wheel effect on 24 frame per second(FPS).

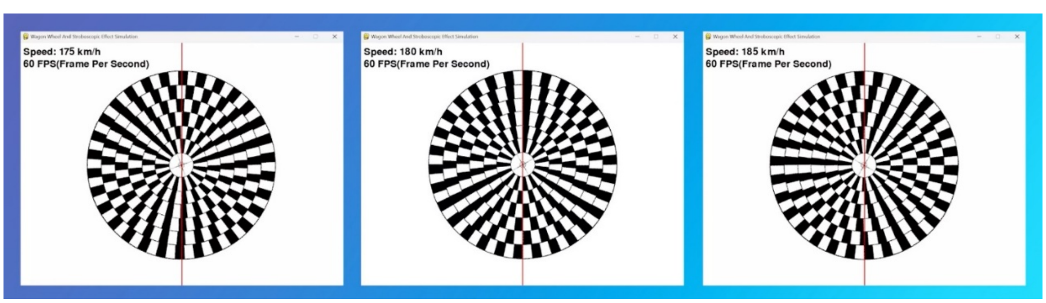

Figure 4. Simulation of wagon wheel effect on 60 frame per second(FPS).

Figures 3 and 4 show the wheel rotation motion simulated at different FPS using python programming language. Different cases of optical illusion were observed by rotating the wheels at different speeds. So, in the figure 3, tests were conducted in the range of 0 km/h - 400 km/h at a frequency of 24 FPS. According to the observation, despite being in motion, the first case of immobility was seen at 72 km/h. Further instances of immobility were observed at speeds of 144 km/h, 216 km/h, 288 km/h, and 360 km/h.

At speeds lower than the listed values, a visual backward movement was observed, and at speeds above the listed values, a visual forward movement was observed. Similarly, this process was repeated at 60 FPS as shown in Figure 4. Inactivity observed in the range of 0 km/h - 400 km/h was observed at speeds of 180 km/h and 360 km/h. In cases below and above these speeds, backward or forward movement was visually observed. In general, numerous unaccounted cases were observed at frequencies of 24 and 60 FPS. The reason for this was the patterns on the wheel. At different speeds, the pattern in each row rotated in different directions. Visual backward movement of the wheel (with all the patterns), stationary state and forward movement were observed in the following cases as we mentioned in the pictures. (24 FPS - 70km/h, 72km/h, 75km/h), (60 FPS - 175km/h, 180km/h, 185km/h).

Taking into account the above, our observations make it possible to note that the state of visual inactivity is observed at speeds of 3 times the value of each FPS. To understand this more clearly, you can watch the video by clicking on the mentioned link.

https://youtu.be/AKyXOJZuy_A

4. Beyond the Illusion: Applications and Considerations

While the wagon wheel effect primarily serves as a captivating optical illusion, its implications extend into practical applications. Understanding and mitigating this phenomenon is crucial in fields such as video production, surveillance, and scientific research. As technology advances, continual efforts are made to refine imaging methods and reduce the occurrence of visual distortions.

The wagon wheel effect, with its intriguing dance of perception and reality, reminds us of the intricacies inherent in our visual experiences. From the early days of photography to the high-speed recordings of the digital age, this phenomenon serves as a reminder that even the most ordinary objects can challenge our understanding when seen through the lens of motion and time.

As we navigate the world of visual illusions, the wagon wheel effect stands as a testament to the ever-present mysteries awaiting discovery in the fascinating realm where science and perception converge.

4.1 Aplication

In information technology, the stroboscopic effect finds application in various areas, leveraging its ability to capture and analyze rapid sequences of images. Here are a few contexts in which the stroboscopic effect is relevant:

1) High-Speed Imaging

In information technology, particularly in the field of high-speed imaging, the stroboscopic effect is harnessed to capture fast and transient events. High-speed cameras, equipped with rapid-flash strobe lighting, can freeze motion and provide frame-by-frame analysis of processes that occur too quickly for the human eye to perceive (Mather & Verstraten 1998; Nıshıda & Sato 1995).

2) Motion Analysis in Computer Vision

Computer vision systems use the stroboscopic effect to analyze and track the motion of objects in video streams. By capturing a series of still frames at high frequencies, these systems can extract valuable data about the trajectory, speed, and behavior of moving objects (Schouten 1967).

3) Display Technologies

Stroboscopic displays are used to enhance the visual experience in certain technologies. For example, in gaming monitors with technologies like NVIDIA G-SYNC or AMD FreeSync, stroboscopic backlighting is employed to reduce motion blur and create smoother visuals, especially during fast-paced gaming scenarios (Wang & Tu 2015).

4) Biometric Recognition Systems

Stroboscopic lighting is sometimes utilized in biometric recognition systems, such as iris or retina scanners. The controlled illumination helps in capturing clear images of the biometric features for accurate identification and authentication (Hao & Cai 2017).

5) Printing and Scanning Technologies

In the context of printing and scanning, stroboscopic illumination is applied to capture precise images of documents or objects moving through the scanning process. This aids in achieving high-quality reproductions and accurate digital representations (Eastman & Campbell 1952).

6) Industrial Automation

Stroboscopic lighting is commonly used in industrial settings for quality control and inspection processes. It helps identify defects or anomalies in fast-moving production lines by providing a series of synchronized images for detailed analysis.

7) Scientific Imaging and Research

In scientific research, especially in fields like physics and chemistry, the stroboscopic effect is employed to study rapid and dynamic processes. Techniques such as fluorescence microscopy or particle tracking often utilize stroboscopic illumination to capture and analyze events at a microscopic scale (Kuller & Laike 1998).

8) Virtual Reality (VR) and Augmented Reality (AR)

In VR and AR applications, where visual fidelity and real-time rendering are crucial, stroboscopic techniques can be employed to optimize frame rates and reduce motion blur. This enhances the overall visual experience for users immersed in virtual or augmented environments. The stroboscopic effect, with its ability to freeze motion and provide detailed insights into dynamic processes, plays a valuable role in enhancing various aspects of information technology, from imaging and display technologies to biometrics and industrial automation.

5. Conclusion

While both effects involve motion and visual perception, the stroboscopic effect relies on the persistence of vision and is often intentional, whereas the wagon wheel effect is an unintended consequence related to aliasing in imaging technologies, leading to perceptual distortions of rotating wheels. As our scientific exploration unfolds, it becomes evident that these optical phenomena not only serve as subjects of inquiry but also present rich avenues for practical application. The deliberate manipulation of the stroboscopic effect, coupled with a comprehensive understanding of its mechanisms and historical contexts, allows for intentional utilization in various fields. Conversely, the inadvertent occurrence of the wagon wheel effect necessitates a vigilant consideration of its real-world implications, especially within the realm of imaging technologies. This review, through its rigorous examination of the underlying mechanisms, historical contexts, and practical implications of the stroboscopic and wagon wheel effects, aspires to contribute significantly to the academic discourse. By shedding light on the intentional and unintentional aspects of these phenomena, this study endeavors to enhance our comprehension of the intricate interplay between science, technology, and human perception. The findings presented herein not only underscore the importance of these optical effects but also pave the way for further exploration and application in diverse scientific and technological domains.

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