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Review: The influence of light on pig welfare

A.J. Scaillierez [a,*], S.E. van Nieuwamerongen - de Koning [a], I.J.M.M. Boumans [a], P.P.J. van der Tol [b], E.A.M. Bokkers [a]

[a] *Animal Production Systems Group, Wageningen University and Research, P.O. Box 338, 6700 AH Wageningen, the Netherlands*
[b] *Agricultural Biosystems Engineering Group, Wageningen University and Research, P.O. Box 16, 6700 AA Wageningen, the Netherlands*

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A B S T R A C T

While several countries impose minimum light requirements for pig housing, it remains unknown whether these requirements are beneficial for pig welfare. Therefore, we aim to review the current knowledge on the effects of light on pig welfare. In this paper, we explain concepts defining light, discuss the relevance of vision for pigs and systematically review the effects of light on pig welfare. Systematic literature searches were performed in two databases to find studies about light and welfare-related topics, including behaviour, health, hormonal secretions and productivity. After screening, 63 studies were reviewed. According to literature, light is relevant in pigs' lives as they are diurnal animals and use vision in combination with other senses to, for example, locate food and interact with conspecifics. Throughout this paper, the investigated light parameters are photoperiod, intensity and spectrum. Pigs seem to have p for a certain light intensity and spectrum, but these preferences vary over production phases. Photoperiod influences feed intake and growth, especially in piglets, but no conclusion can be drawn because of contradictory results. Furthermore, pigs' activity patterns adapt to the provided light schedule and show a diurnal rhythm with higher activity during lit hours. Photoperiod also plays a role in the diurnal secretion of hormones. Cortisol secretion increases shortly before the moment of light onset, and melatonin secretion is influenced by the light and dark contrast with a nocturnal rise after light offset. Some behaviours are impacted by light intensity; for instance, dim conditions are associated with resting and bright conditions with elimination behaviour. Moreover, a few studies showed that in dimmer conditions, more negative social interactions occur, while brighter conditions lead to more positive interactions. Lastly, even though light spectrum is the least explored light parameter, several studies showed that UV B light can activate the cutaneous synthesis of vitamin D_3. A limitation in the current literature is that several studies tested light treatments differing in more than one light parameter, making the interpretation of each light parameter difficult. Moreover, most studies do not provide information on other light parameters not targeted by the study, particularly on light spectrum. Some clear knowledge gaps that emerged from this review are on light spectrum and on affective states of pigs in relation to light.

Implications

European Union legislation requires a minimum of 40 lux with a photoperiod of 8 h a day in pig housing, but scientific evidence justifying these requirements is limited. Until now, research focussed on the role of light on pigs' productivity and reproduction. After systematically reviewing the literature, photoperiod, light intensity and spectrum affect specific aspects of behaviour, health, hormonal secretion and productivity. Although there is increasing interest in considering affective states in welfare research, the role of light on pigs' affect remains unknown. Furthermore, new light technologies (light emitting diodes) offer new opportunities in light management that may affect pig welfare.

Introduction

Housing conditions are known to influence pig (*Sus scrofa domesticus*) welfare (Broom, 1991; Ludwiczak et al., 2021). The consequences of housing aspects such as indoor temperature, space allowance, air quality and provision of enrichment on pig welfare have been extensively documented (Kittawornrat and Zimmerman, 2011; Whittaker et al., 2012; Vermeer and Hopster, 2018; Chidgey, 2024). The effects of light conditions on pig welfare, however, have received little attention, despite recognised impacts on the welfare of other species, such as poultry (as reviewed by Manser, 1996; Prescott et al., 2003; Patel et al., 2016; Rana and

* Corresponding author.
E-mail address: alice.scaillierez@wur.nl (A.J. Scaillierez).

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Campbell, 2021; Wu et al., 2022) and laboratory animals (as reviewed by Peirson et al., 2018).

As highlighted by Taylor (2010), there is no clear science-based recommendation nor consensus for minimum light requirements in pig houses. In the European Union and the United Kingdom, pigs have to be kept under a light of at least 40 lux for a minimum period of 8 h per day (European Union, 2008; Agriculture and Horticulture Development Board, 2019). Additional requirements to these minimum standards, such as providing daylight or 80 lux as a minimum light intensity, are imposed by some European countries (Belgium, Austria, Sweden, Germany) or in certain welfare schemes such as 'Beter Leven' in the Netherlands (Beter Leven Keurmerk, 2018). Canadian legislation requires a light period of at least 8 h per day with a minimum of 50 lux and access to a dark area of less than 5 lux for at least 6 h per day (National Farm Animal Care Council, 2014). Australia and New Zealand impose the provision of light (natural or artificial) for a minimum of 9 h a day with an intensity of at least 20 lux at pig level (Primary Industries Standing Committee, 2008; National Animal Welfare Advisory Committee, 2018).

Among the various legislative measures, two aspects of light are consistently mentioned: photoperiod (i.e. period of the day during which light is provided) and light intensity (i.e. brightness of light). However, no clear scientific consensus supports these requirements (Taylor, 2010).

The objective of this paper was to review the current knowledge on the effects of light on pig welfare. This review includes three sections: (1) a narrative section defining the light aspects covered in this review, (2) a narrative review of the functioning and importance of vision for pigs, and (3) a systematic literature review on the effects of light on pig welfare.

To organise findings from the existing literature, the framework of animal welfare developed by Fraser (2008) is used. This approach defines animal welfare through three partly overlapping components that should be addressed: basic health and functioning (ensuring freedom from injury, disease, stress and satisfied basic life requirements), natural living (allowing the expression of natural behaviours), and affective state (minimising negative and maximising positive affect) (Fraser, 2008; Webb et al., 2019).

In the component of basic health and functioning, we excluded reproductive performance since several reviews have already been published on this topic (e.g. Claus and Weiler, 1985; Prunier et al., 1996; Flowers, 1997, 2022; Andersson, 2000; Peltoniemi and Virolainen, 2006), and reproductive performance in itself is not considered to be an animal welfare issue. Lastly, limitations emerging from this review are discussed, recommendations for future research are made and conclusions on the current knowledge about light and pig welfare are provided.

Material and methods

The literature search was conducted in March 2023, and the systematic review protocol for animal intervention studies developed by the Systematic Review Centre for Laboratory animal Experimentation was followed (version 2.0, De Vries et al., 2015). The literature search was performed separately in PubMed and Web of Science where three different search strings were applied to both databases. The three search strings consisted of one wide search and two narrower search strings. The first search conducted was a wide search to ensure the inclusion of all possible relevant papers, including keywords related to pigs and light. An exclusion term with several different keywords was added to avoid retrieving too many irrelevant papers about non-target animals or papers not related to animal husbandry. The second search performed included keywords related to pigs and light and welfare or health. The search string used for the first search was reused and extended by adding terms such as; welfare, health, BW, lameness, lesion, feed intake and circadian rhythm. Exclusion terms were added to remove papers from irrelevant fields. Lastly, the third search included keywords related to pigs and light and behaviours or emotions. The first search string was reused and completed with specific search terms such as animal behaviour, activity, exploration, feeding behaviour, social behaviour, agonistic behaviour, stereotypies, as well as emotion, affect and mood. Exclusion terms about non-target animals or irrelevant fields were added. Exact search strings for all searches are available in Supplementary Table S1.

In both databases, the filter option was used on every search string to only keep peer-reviewed articles and to exclude reviews and papers in languages other than English. In PubMed, 2 657 papers were retrieved for the first string, 556 for the second string and 363 papers for the third string. In Web of Science, 2 483 papers were retrieved for the first string, 654 for the second string and 404 for the third string (Fig. 1). All papers found were exported from the databases and imported and merged in the reference manager EndNote21 (version Bld 17096, Clarivate, the United States). After removing duplicates, 2 608 papers were kept from the first search string used in PubMed and 1 286 were kept from the first search string used in Web of Science. The second and third search strings did not retrieve new papers that were not already identified from the first search string across both databases.

The 3 894 remaining papers were then assessed for relevance using the open-source machine learning tool ASReview LAB (version 1.1.1, Van De Schoot et al., 2021). This tool accelerates the screening process by ranking papers on relevance (Van De Schoot et al., 2021). It is based on a machine learning-aided pipeline that applies active learning to continuously optimise the order of the most relevant papers (Van De Schoot et al., 2021). The order of papers from the most to the least relevant, proposed by ASReview LAB, was then manually screened paper by paper by one assessor (A.S.). In total, the assessor screened 1 279 papers based on their title and abstract, of which 4.31% (168 papers) were considered relevant. When no relevant paper was identified in 390 consecutive papers (representing 10% of the dataset), the title and abstract screening was stopped as proposed by Haastrecht et al., 2021. In addition, to ensure that no relevant paper was left out from screening, all titles of the 2 615 remaining papers were checked, and none of these were considered relevant to the topic of this review.

The full texts of 168 relevant papers were then screened for eligibility. Papers corresponding to any of the following exclusion criteria were removed: literature reviews and conference proceedings (7 papers), absence of full text (21 papers), duplicate of a paper already present in the dataset (two papers), not comparing at least two different light treatments simultaneously (leading to possible confounding seasonal effects, 47 papers), tests assessing pig vision (two papers), using pigs that underwent surgery (eight papers), insufficient information on the statistical method used (four papers). In total, 91 papers were excluded in this eligibility phase.

Forward and backward snowballing was performed on the 77 remaining papers, with the selection process relying on the titles of papers. This resulted in 16 new papers that did not appear in the systematic review process (neither retrieved by searches nor previously rejected in earlier phases). Full texts of these 16 papers were then screened with the same exclusion criteria (as presented above), resulting in the exclusion of 11 papers: for being a review (one paper), due to unavailability of its full text (one paper), for not comparing at least two light treatments simultaneously (six papers), and for lacking information on statistical methods (two papers) or on light treatments (one paper). Papers focusing exclusively on the role of light on pig reproduction were removed from the final dataset (19 papers). Ultimately, 63 papers were included in the systematic review.

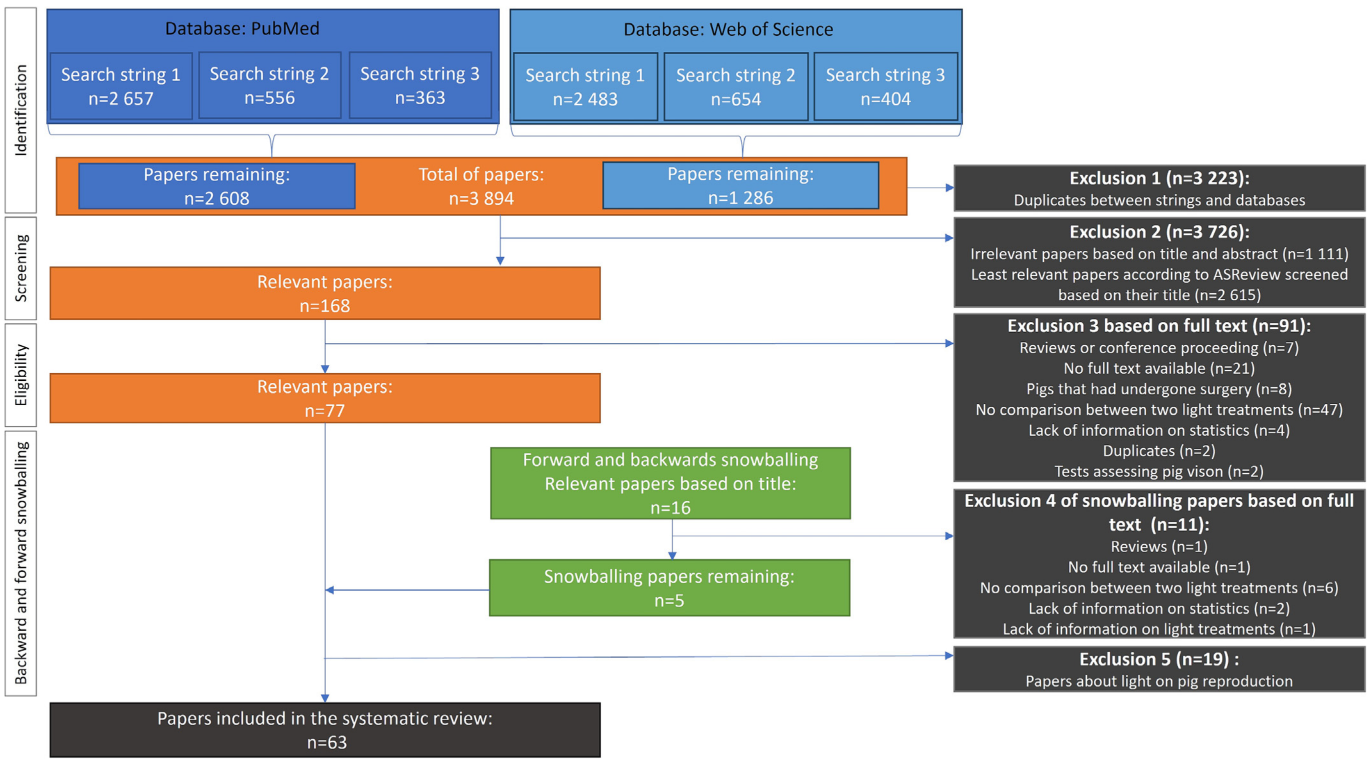

Fig. 1. Diagram of the systematic review process on the influence of light on pig welfare.

Fundamentals of light

Characterisation of light

In this section, the concepts behind light are explained and illustrated through human vision.

Light is defined as electromagnetic radiation that propagates energy waves in the form of photons through space. The amount of energy displaced by these waves is proportional to the wavelength measured in nanometres (nm). Light is categorised by its wavelength (Fig. 2), i.e. UV (wavelengths ranging from 100 to 400 nm), human visible light (from 380 to 780 nm) and IR light (from 750 nm to 1 mm) (Zwinkels, 2015). In practice, exposure to light can be defined by three aspects; the photoperiod, the intensity and the spectrum.

Photoperiod refers to the duration of light exposure within a 24-h cycle and is expressed as a ratio of lit (**L**) hours known as photophase over dark (**D**) hours known as scotophase, such as 8L:16D (Agriculture and Horticulture Development Board, 2019). Furthermore, the times of the lit period are often mentioned, as the photoperiod alone does not specify whether the light exposure is continuous or interrupted in shorter intervals nor whether light exposure happens during daytime or nighttime.

Light intensity, also called illuminance, represents the quantity of visible light emitted by a light source (also known as luminous flux) that is received by a surface at a specified distance. Light intensity is measured in lux and is calculated by dividing luminous flux (measured in lumen) by the area in square metres (Thimijan and Heins, 1983). One lux is equivalent to one lumen per square metre. In the imperial system of units, lux is replaced by the foot-candle where one unit equates to one lumen per square foot (Thimijan and Heins, 1983).

The spectrum of a light source is determined by the amount and wavelength range of the radiation produced. In the visible part of the light spectrum (i.e. excluding IR and UV), every wavelength is associated with a colour (Fig. 2). From the lowest to the highest wavelength, the colours are violet, blue, green, yellow, orange and red (Zwinkels, 2015). Depending on their spectral composition, lights can be distinguished as monochromatic or heterochromatic. Monochromatic lights (e.g. lasers) consist of photons with a similar energy level and are thus characterised by a unique wavelength. Most light sources, however, contain several wavelengths (e.g. Light Emitting Diodes known as **LED**, incandescent or fluorescent lights) or all visible wavelengths (e.g. daylight). The light colour perception depends on the presence of photoreceptors in the eye and the neural processing of light signals captured by photoreceptors (Kelber et al., 2003). Humans, for example, possess photoreceptors sensitive to red, green and blue wavelengths, in which light containing these three light colours or all colours (e.g. in LED or daylight) will appear close to white (Zwinkels, 2015).

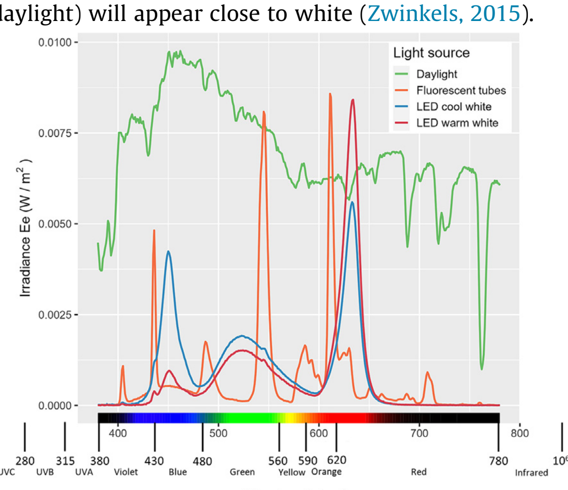

Fig. 2. Examples of spectral measurements[1] from daylight (4 723 K), fluorescent tubes (3 787 K), LED with cool white spectrum (6 235 K), LED with warm white spectrum (2 572 K) in pig houses. Abbreviations: LED = light emitting diode, UV = ultraviolet, UVA = ultraviolet A, UVB = ultraviolet B, UVC = ultraviolet C. [1]measurement range of the spectrophotometer used: 380–780 nm.

The proportion of each wavelength in light can be visualised by the spectral power distribution, representing the energy amount (irradiance or flux density) as a function of wavelength (Zwinkels, 2015; Durmus, 2022). Different light sources can be recognised by their distinctive spectral distribution as shown in Fig. 2.

For near-white light sources, correlated colour temperature (**CCT**) measured in kelvin is the most widely used metric in lighting research for colour appearance. Light spectra that appear yellowish or reddish to humans have a low CCT (around 2 700 K) and are considered as "warm white", while light spectra with bluish tones have a high CCT (around 6 500 K) and are considered as "cool white" (Blume et al., 2019; Durmus, 2022).

Photoperiod, intensity and spectrum are used to describe light exposure. In most artificial light sources, these characteristics are static and defined either by the light type (e.g. intensity and spectrum) or by the user (e.g. photoperiod, intensity for dimmable light and spectrum for tuneable light). Conversely, daylight is a light type that remains uncontrollable and hardly predictable as photoperiod, intensity and spectrum vary over time. Photoperiod varies over the year (except at the equator), intensity depends, for example, on the time of the day and the cloud coverage, and spectrum varies over the day due to the angle of the sun (Agriculture and Horticulture Development Board, 2019).

Daylight or artificial light; consequences of other parameters

A special feature of daylight is the presence of UV wavelengths in its spectrum. Four types of UV radiations produced by daylight are ultraviolet A (**UVA**), ultraviolet B (**UVB**), ultraviolet C (**UVC**) and vacuum UV (Fig. 2). All vacuum UV, UVC, and a substantial part of UVB (99.9%) and UVA (95%) radiation are filtered out by the ozone layer in the atmosphere, and only the remaining percentages can reach Earth's surface (Holick, 2016). Moderate UVB exposure can be beneficial as it enables the skin to synthesise vitamin D_3. Vitamin D_3 is involved in bone mineralisation and is thought to reduce the risk of autoimmune and cardiovascular disease (Bendik et al., 2014; Holick, 2016). Additionally, as shown by in vitro studies, UVA and UVB radiation influenced the expression of genes regulating the circadian rhythm as well as the production of beta-endorphin, a hormone associated with feelings of relaxation and well-being (Veening and Barendregt, 2015; Holick, 2016). Yet, UVA exposure can be harmful as it is responsible for DNA, RNA and protein damage, caused by the formation of free radicals, increasing the risk of skin cancer in humans (Holick, 2016).

UV exposure is quantified using the standard erythema dose (**SED**). The SED considers both the intensity of the UV radiation at the skin contact point and the spectrum of the UV light source, as each wavelength has a different potential to activate vitamin D_3 synthesis or cause a sunburn (i.e. erythema) (Diffey et al., 1997). The SED received can vary according to the duration of exposure or the receiver's distance to the UV light source.

Lastly, artificial light sources receive quick fluctuations of power called flicker that can be perceived by humans if a light source is malfunctioning. Flicker perception in humans has been reported to cause visual headaches, migraines and visual fatigue (Taylor, 2010). The flicker sensitivity of pigs remains unknown, but is thought to be similar to cats, suggesting for example that flicker from failing fluorescent light can be perceived by pigs (Taylor, 2010). Pigs' vision and light perception are further discussed in the following section.

Pigs' vision in relation to their environment

Importance of vision for pigs

Vision is one of the senses used by pigs for their basic functioning, such as finding food resources, communicating with conspecifics and detecting danger (Taylor, 2010). Next to olfaction and touch, sight is a relevant sensory component as some studies showed that pigs can use different colour cues (Tanida et al., 1991; Croney et al., 2003; Deligeorgis et al., 2006) or mirrors to locate food (Broom et al., 2009). Even though pigs rely substantially on the combination of olfactory, auditory and tactile stimuli, vision is also involved in social contexts. Establishing and maintaining a hierarchy does not necessarily rely on vision alone (Ewbank et al., 1974), but pigs are able to discriminate between familiar conspecifics in the absence of olfactory or auditory signals (McLeman et al., 2008). Furthermore, Nicol and Pope (1994) reported that visual signals were more effective than olfactory ones in the context of social learning, and pigs use visual signals to communicate during social interactions, such as aggression or submission (Jensen, 2002). Therefore, vision, albeit together with other senses, plays a role in the display of these important behaviours in pigs. Moreover, as often found in prey species, pigs possess lateralised eyes leading to a large angle of view (approximately 310°) allowing them to constantly monitor their environment (Zonderland et al., 2008). Their vision is mainly monocular on the sides, binocular on 30–50° in front of them, with a blind spot behind their body (Middleton, 2010).

Anatomy of pigs' eyes

Light goes through pigs' eyes to reach the retina, while the iris muscle dilates or contracts to control the pupil's diameter and hereby affects the amount of light received by the retina. The pupil's shape provides insight into the eye's capacity to adapt to varying light intensities without impairing the retinal function. For instance, circular pupils are prevalent in diurnal animals, whereas nocturnal animals often exhibit horizontal or vertical slit-shaped pupils on contraction (Land and Nilsson, 2012) that are more efficient at blocking bright light and protecting eyes from daylight. Pigs' pupils are circular when dilated and slightly oval and horizontal when contracted, suggesting a predisposition for exposure to moderately intense daylight (Taylor, 2010; Land and Nilsson, 2012).

In line with the limited suitability for bright light conditions, pigs do not have corpora nigra (Middleton, 2010). These structures, which further reduce the entrance of light in the eyes, are found in species adapted to bright light such as horses (Middleton, 2010). Furthermore, Dureau et al. (1996) observed retinal degeneration when continuously exposing minipigs to an intensity of 2 500 lux (intensity level that can be reached in the presence of daylight). Similar to many diurnal animals, pigs lack a tapetum lucidum, a structure commonly found in nocturnal species that serves as a reflective system to enhance the visual sensitivity in dim conditions (Ollivier et al., 2004). In summary, the pupil shape and the absence of tapetum lucidum and corpora nigra suggest that pigs' eyes are adapted to lit environments, although not optimally suited for extremely bright light conditions (Taylor, 2010).

Once light enters the eye, the luminous signal is processed by two types of photoreceptors contained in the retina (i.e. cones and rods). Cones are activated in photopic conditions (low to high light intensities) and rods allow scotopic vision (at very low light intensities) (Peichl, 2005). The ratio of cones to rods differs across species and indicates whether the retina is best adapted for scotopic or photopic vision (Peichl, 2005). Despite having a rod-dominated retina with a cone:rod ratio of 1:8 (Chandler et al., 1999), suited for low-light conditions, pigs are diurnal animals (Peichl, 2005). This contradiction is found in other diurnal species and is believed to be a trait inherited from nocturnal ancestors (Peichl, 2005).

Pigs' colour perception and acuity

The spatial distribution of rods and cones in the retina affects the quality of vision (Chandler et al., 1999). Pigs have a large horizontal zone called area centralis where the cones are more densely packed than in the rest of the retina (Hendrickson and Hicks, 2002; Vrolyk et al., 2020) and this is the region where light reaches the retina and which produces their highest visual acuity (Mustafi et al., 2009).

Not only the concentration of cones is important in vision, but also their type. Colour perception is possible when at least two distinct cone types are present, as each type of cone is most sensitive to a particular part of the light spectrum (Land and Nilsson, 2012). Pigs possess two types of cones; short-wavelength-sensitive cones that are maximally sensitive at 439 nm (blue) and medium-wavelength-sensitive cones maximally sensitive at 556 nm (green) (Neitz and Jacobs, 1989). Therefore, pigs are suggested to have dichromatic vision which limits the distinction between green and red colours, also known in humans as colour blindness or protanopia (Hendrickson and Hicks, 2002). This differs from trichromatic human vision, as the human retina also contains long-wavelength-sensitive cones which are sensitive to red. The density of short-wavelength-sensitive cones is higher in pig retinas (13.5% of cone population, Hendrickson and Hicks, 2002) than in human retinas (5%, Mustafi et al., 2009) suggesting that pigs may be more sensitive to blue light than humans, and perceive this colour as brighter than the rest of the light spectrum. In addition, it was reported that pigs cannot perceive IR (Taylor et al., 2006) since they lack long-wavelength-sensitive cones, and their perception of UV remains unclear as it is unknown how short and medium-wavelength-sensitive cones process UV wavelengths (Douglas and Jeffery, 2014).

The overall morphology of pigs' eyes is also relevant to their visual acuity. The outer structure called the cornea protects the eye and focuses light on the retina (Abhari et al., 2018). Pigs' sclera, the "white" part of the eye, which protects and supports the eyeball, is thicker and has a larger diameter than in humans that could result in a greater astigmatism reducing pigs' visual acuity (Faber et al., 2008; Sanchez et al., 2011). The ciliary muscle is another structure that alters the shape of the lens in order to facilitate focusing on objects at varying distances (Land and Nilsson, 2012). In pigs, the ciliary muscle is small and does not function as an accommodative muscle (May et al., 2005), which suggests

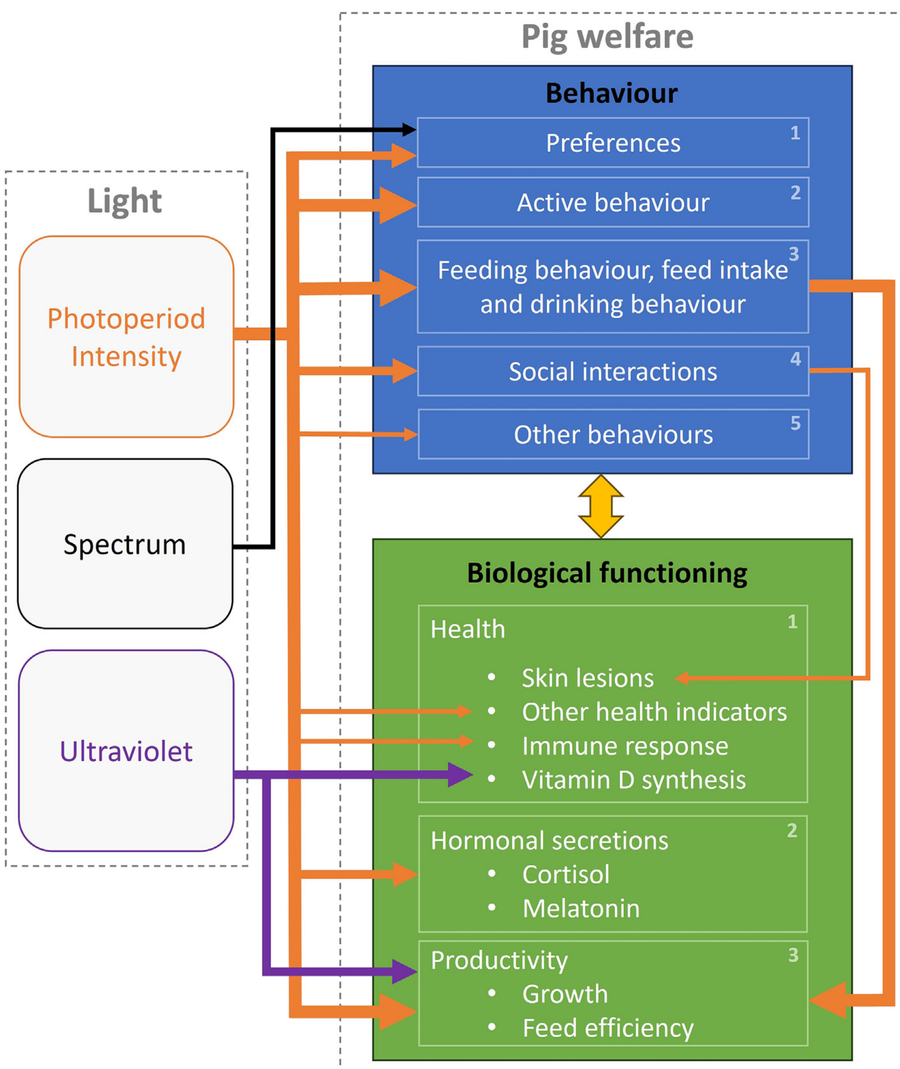

Fig. 3. Schematic overview of the systematic literature review results on light and pig welfare. The two coloured blocks represent welfare components, in which white outlined boxes represent subsections, and numbers in the top right corner correspond to the subsection order in the review. Arrows represent relations that were reported in papers and are described in this review. The arrow thickness indicates the number of papers found (<5 for the thinnest, ≥5 and ≤ 10 for the medium, >10 for the thickest). The yellow arrow indicates an overall interaction between welfare components.

that the acuity for moving objects, especially in short viewing distances, may be poor (Taylor, 2010).

One study investigated whether the quality of vision could be affected by lighting conditions by using a Landolt ring test with different cue sizes (Zonderland et al., 2008). Even though under lower light intensities (range tested: from 0.5 to 80 lux) pigs made more incorrect choices, higher intensities did not result in more correct choices. Moreover, visual acuity was more affected by the size of the cues than lighting conditions (Zonderland et al., 2008). Therefore, it remains unclear whether light intensity affects pigs' acuity and the perception of their environment, furthermore, the role of light spectrum in pigs' acuity has never been explored.

Lastly, pigs' perception of their environment is likely affected by the light installation and barn designs. The location of light sources can create brighter and dimmer areas in the pen, and the light source shape can result in a more centred or scattered light (e.g. with a bulb or a tube). Regarding the barn design, window positioning creates variability in light distribution within a barn, obstacles (e.g. feeder pipes or pen partitions) can create shadows, and wall colours can affect light reflection, and consequently light perception of pigs.

Light and pig welfare

In this section, the results of papers retrieved for the systematic review are discussed. A schematic overview of the potential effects of light parameters on different aspects of pig welfare is provided in Fig. 3. Furthermore, all papers related to light and pig behaviour can be found in Table 1, and papers about light and pig biological functioning in Table 2. These two tables provide references included in this systematic review ordered by welfare aspect measured, light parameter investigated and pigs' production phase.

Light and pig behaviour

Table 1
Overview of the studies investigating the effects of different light parameters on pig behaviour at different production stages. References are numbered and cited below this table. Combinations of light parameters tested are detailed with P standing for photoperiod, I for intensity and S for spectrum.

Theme	Light parameter(s)	Production stage	Citation
Preference tests	Photoperiod	Growing-finishing pigs	[4, 5]
	Intensity	Suckling piglets	[59, 46]
		Weaned piglets	[62, 18]
		Growing-finishing pigs	[5]
	Spectrum	Suckling piglets	[52]
		Weaned piglets	[17]
	Combined parameters	Suckling piglets	[30 (I and S)]
Activity	Photoperiod	Suckling piglets	[29, 57]
		Weaned piglets	[32, 15, 21]
		Growing-finishing pigs	[40]
		Sows and boars	[57]
	Intensity	Weaned piglets	[10, 54]
		Growing-finishing pigs	[39, 26]
		Sows and boars	[9]
	Combined parameters	Growing-finishing pigs	[38 (P and I), 51 (I and S)]
		Sows and boars	[35 (P, I and S)]
Feeding behaviour or feed intake	Photoperiod	Suckling piglets	[36, 57, 41, 29]
		Weaned piglets	[41, 8, 29, 15, 25, 21]
		Growing-finishing pigs	[40]
	Intensity	Weaned piglets	[10]
		Growing-finishing pigs	[39, 26]
		Sows and boars	[9]
	Combined parameters	Suckling piglets	[35 (P, I and S)]
		Weaned piglets	[14 (P, I and S)]
		Growing-finishing pigs	[38 (P and I)]
Drinking behaviour	Photoperiod	Weaned piglets	[21]
		Growing-finishing pigs	[40]
	Intensity	Weaned piglets	[10]
		Growing-finishing pigs	[39, 26]
Social interactions	Photoperiod	Weaned piglets	[21]
		Sows and boars	[23]
	Intensity	Weaned piglets	[10, 54]
		Growing-finishing pigs	[39]
		Sows and boars	[9]
	Combined parameters	Weaned piglets	[14 (P, I and S)]
		Growing-finishing pigs	[38 (P and I)]
Other behaviours	Photoperiod	Weaned piglets	[21 (play, ear and tail manipulation)]
		Growing-finishing pigs	[40 (exploration, bar biting)]
	Intensity	Weaned piglets	[50 (play)]
		Growing-finishing pigs	[39 (exploration, bar biting), 26 (exploration, ear and tail manipulation)]
	Combined parameters	Weaned piglets	[14 (P, I and S, ear and tail manipulation)]
		Growing-finishing pigs	[51 (I and S, elimination)]

4 (Baldwin and Meese, 1977), 5 (Baldwin and Start, 1985), 8 (Bruininx et al., 2002), 9 (Canaday et al., 2013), 10 (Christison, 1996), 14 (Glatz, 2001), 15 (Gomes et al., 2018), 17 (Götz et al., 2020), 18 (Götz et al., 2022), 21 (Griffioen et al., 2023), 23 (Harris and Gonyou, 2003), 25 (Katsumata et al., 2018), 26 (Kim et al., 2021), 29 (Lachance et al., 2010), 30 (Larsen and Pedersen, 2015), 32 (Lay et al., 1999), 35 (Liu et al., 2022), 36 (Mabry et al., 1982), 38 (Marinelli et al., 2020), 39 (Martelli et al., 2010), 40 (Martelli et al., 2015), 41 (McGlone et al., 1988), 46 (Morello et al., 2019), 50 (O'Connor et al., 2010), 51 (Opderbeck et al., 2020), 52 (Paggi et al., 2020), 54 (Parker et al., 2010), 57 (Simitzis et al., 2013), 59 (Tanida et al., 1996), 62 (Taylor et al., 2006).

Preferences in relation to light

In order to understand the importance of light for pigs, a few studies conducted preference tests. In preference tests, the animal can choose to expose itself to a certain condition among a range of options (Fraser and Nicol, 2018).

In a set of preference tests with growing-finishing pigs, Baldwin and Meese (1977) provided two photoelectric beams of 0.4 lux; one switching lights on at 350 lux, and the other switching lights off. When pigs were exposed to darkness at the start of a 6-h test, they activated the beam providing light more than the beam providing darkness. While when starting the test in the light, no difference was found in the use of darkness or light beams. Similar observations were reported when authors conducted the test for longer periods of 3 and 7 days. In another test, pigs provided themselves with light for 72–78% of the time and no extended periods of darkness were reported as pigs created several short dark periods over the day throughout the 4-day test (Baldwin and Meese, 1977).

In another study, Baldwin and Start (1985) tested the willingness of growing-finishing pigs to activate IR beams for either a light or a darkness reward (intensities not reported) lasting 40 s, compared to a beam that was not rewarding (control beam). After a habituation period to the test pen under daylight, when pigs were kept in continuous darkness during the test, the rewarding beam provided light. The use of the light-rewarded beam was numerically higher (a total of 1.5–2 h of light per 24 h) than the use of the control beam (if the control beam was rewarded, it would have led to about 50 min of light per 24 h), however, no statistical analysis was performed. When pigs were kept in continuous light during the test, the beam use did not differ whether it was rewarded with 40 s of darkness or not rewarded (about 35 min per 24 h for each). In addition, the use of the light-rewarded beam for 40 s followed a diurnal pattern with a numerically increased light duration between 0800 and 2100 h, and the highest light duration observed from 1500 to 1700 h with more than 10 min of light per hour. Baldwin and Start (1985) also investigated pigs' motivation to activate lights at two intensities. In the presence of one beam providing continuous light at 110 lux and another turning lights continuously off, pigs kept lights on for 54% of the time (24 h). When the light intensity was reduced to 10 lux, pigs kept lights on for 63% of the time (24 h). The light duration per day remained constant over the test period of 5 days and no diurnal pattern for light activation was observed in this experiment.

Another type of preference test consists of providing access to chambers with different light conditions. The preference of weaned piglets for light intensity was investigated in four chambers with light intensities of 2.4, 4, 40 and 400 lux (Taylor et al., 2006). Pigs stayed longer in the 2.4 lux chamber than in the 40 and 400 lux ones, longer in the 4 lux chamber than in the 400 lux one and no significant differences were found for other comparisons between chambers. This preference to spend more time in darker intensities did not change between 7 and 11 weeks of age (Taylor et al., 2006). On the other hand, the preference between darkness (0 lux) and 600 lux did change in pigs from 5 to 9 weeks of age (Götz et al., 2022). The authors reported a preference for light at 5 weeks of age, and a preference for darkness at 7 weeks. At 9 weeks of age, this preference became less consistent over the day with darkness being preferred for 22 out of 24 h (yet no light intensity by time of the day interaction effect was given). Overall, pigs were in the 600 lux chamber for 58.3% of the observations, and for the rest of the time in the dark chamber.

In Taylor et al. (2006), pigs preferred to be inactive under dimmer intensities (2.4 and 4 lux) while no difference in inactivity was found under 40 and 400 lux. Pigs did not show a preference for intensity when being active. In addition, Taylor et al. (2006) did not find any clear diurnal pattern in the occupancy of areas with different intensities. Götz et al. (2022) observed more active pigs (defined as not lying or eating) in the lit compartment (600 lux) early in the morning (0400–0600 h) and in the afternoon (1200 and 1600 h) at 5 weeks of age, but this preference became less clear over the weeks.

With respect to specific postures and active behaviours, increasing light intensity was associated with less ventral lying and lateral lying and more elimination (2.4, 4, 40, 400 lux, Taylor et al., 2006). Pigs showed standing, sitting, moving, eating, drinking, rooting, playing and interacting with pen mates at similar frequencies in the chambers with various light intensities (Taylor et al., 2006). Götz et al. (2022) also found that lying behaviour was influenced by light intensity and the time of day. Unlike Taylor et al. (2006), Götz et al. (2022) observed more lying pigs in light than in darkness at 5 weeks of age, however, preferences for lying in darkness were found at 7 and 9 weeks of age, which is similar to results of Taylor et al. (2006). Furthermore, Götz et al. (2022) observed more faeces in the lit compartment than in the dark one, which supports findings from Taylor et al. (2006), who observed more elimination behaviour under higher intensities than under dim light. Also, more feeding behaviour was observed under 600 lux than under darkness between 0400 and 1600 h at 5 weeks of age (Götz et al., 2022). However, from 7 to 9 weeks of age, this preference faded with both 600 lux and darkness being preferred at different times of the day, and no difference in feed intake was found between 600 lux and darkness (Götz et al., 2022).

In another preference test, Götz et al. (2020) tested the preference of weaned piglets for light spectrum by providing a warm white compartment with a CCT of 3 000 K and a cool white compartment of 6 500 K. Piglets of 5 weeks of age stayed more under warm white lights throughout the day (except between 1600 and 1800 h). However, this preference declined over time, as at 7 weeks of age, warm white was only preferred from 0700 to 0800 h, and at 9 weeks of age, no more preferences between light spectra were found. Piglets' preference to display active behaviour (i.e. performing activities other than eating and lying) was inconsistent among spectra, with warm white being preferred at 5 weeks of age, followed by a switch to more active piglets in cool white, for a few hours at 7 weeks of age and throughout the day at 9 weeks of age (Götz et al., 2020). Light spectrum and the time of the day affected lying behaviour, in that warm white was consistently preferred at 5 weeks of age, but this preference declined and was reported in 7 of the 11 time blocks observed at 7 weeks of age, and in three out of 11 at 9 weeks of age (Götz et al., 2020). Feeding behaviour of 5-week-old piglets occurred more in the warm white compartment. It switched to more occurrence under cool white in 9 of the 11 observed time blocks at 7 weeks of age and for all time blocks at 9 weeks of age. This observation was confirmed as more feed intake was reported in the cool white compartment (Götz et al., 2020). Lastly, more faeces were observed throughout the experiment in the cool white compartment than in the warm white one, suggesting more elimination behaviour in cool white light (Götz et al., 2020).

Piglets' light preference was also investigated with the objective of making the creep area more attractive and providing adapted thermal conditions and shelter from crushing by the sow. The preference of 1-week-old piglets was studied by Tanida et al. (1996) by measuring the latency to enter a chamber with different light treatments in the presence of nursing grunts, i.e. light (2 100 lux), darkness (5 lux), flashlight from the front and towards the piglet (160 lux) and flashlight from behind and towards the piglet. Piglets exhibited the shortest latency when moving from a dark to a lit chamber compared to going from light to dark, light to light or dark to dark, indicating that piglets in the dark were attracted by light. Less individual variation in latency was observed when piglets moved from dark to light than from light to dark. When placed in a lit chamber, piglets moved faster to another lit chamber than to a dark one. Exposure to a flashlight illuminating the other chamber, whether from the front or behind the piglet, resulted in quicker movements compared to moving to a dark chamber (Tanida et al., 1996).

Larsen and Pedersen (2015) tested the provision of light in addition to heat by comparing a heat source without light, a heat source providing white light (LED, 130 lux) and a commonly used IR heat lamp (incandescent light, 130 lux). During the day, the use of the creep area did not differ whether the heat source was illuminated or not, but in the evening, more piglets were present under the non-illuminated heat source. This result suggests that piglets prefer being exposed to a warm but dark resting place in the evening. The authors did not report if the light contrast between the heat source with and without light was as clear during the day (presence of artificial light and daylight at 300 lux) compared to the evening (no artificial light and daylight). The absence of a difference during daytime could therefore be explained by either an absence of preference for either light or darkness (possibly due to sow-piglet interactions) or a possible overspill of ambient light in the unlit creep area resulting in a less clear light contrast between illuminated and non-illuminated heat sources. The latter hypothesis is supported by a study from Morello et al. (2019), in which piglets spent more time in a bright (300 lux) than in a dim (4 lux) creep area. No differences were found between the bright and dim creep area in the latency to enter the creep, and in creep occupancy. Moreover, the 300 lux creep did not affect sows' space use and posture in loose farrowing pens.

Furthermore, light spectrum seems to affect piglets' creep area occupancy. Paggi et al. (2020) found that piglets remained more under white light than under blue or red light, but no difference was found between white light and yellow or green lights. These results could be explained by the spectral sensitivity of pigs that are thought to be more sensitive to blue and less sensitive to red light (Taylor, 2010).

To summarise, when given the choice to turn lights on or off, pigs kept lights on for more than half of the day. This preference seemed similar regardless of the intensity. Overall, piglets seem to prefer a lit creep area during the day and an unlit creep area in the evening and a white light source over monochromatic blue or red light. Growing-finishing pigs' preferences for light intensity and spectrum are less clear with preferences that seem to change over weeks. Based on the limited number of studies, pigs seem to display more resting behaviour under darkness or dimmer light and more elimination behaviour under brighter light.

Active behaviour

This section outlines the effects of fixed light treatments differing in photoperiod, light intensity or spectrum (on which pigs have no control, unlike preference tests), on pigs' behaviour. Studies in this domain have explored behaviours such as activity levels, feeding, elimination, social interactions, exploration, play and manipulative behaviours. General activity has been assessed through diverse methods, including observing posture (with lying and standing pigs as indicators of inactivity and activity respectively), combining posture with action (e.g. piglets lying and nursing at the udder considered as active), and observing locomotory behaviour.

Out of six studies, three found an effect of photoperiod on overall activity levels (Lay et al., 1999; Simitzis et al., 2013; Martelli et al., 2015) and three others found no effect (Lachance et al., 2010; Gomes et al., 2018; Griffioen et al., 2023). Six-day-old suckling piglets exposed to 20L:4D stood more than piglets under 8L:16D (Simitzis et al., 2013). Lachance et al. (2010) did not find differences in activity between 23L:1D and 8L:16D photoperiods; however, their definition of activity included other behaviours and was defined as "standing, sitting and piglets lying active at the udder".

In weaned piglets, where activity was considered as standing while performing another behaviour, no difference was found between continuous light (24L:0D) and a diurnal light schedule (12L:12D) (Lay et al., 1999). While statistical confirmation for the interaction between light treatments and observation days is lacking, weaned piglets were numerically more active for 5 non-consecutive days out of 12 observation days when exposed to continuous light in comparison with exposure to a diurnal photoperiod (Lay et al., 1999). Two other studies in weaned piglets did not find any effect of photoperiod on activity comparing 23L:1D with 12L:12D (Gomes et al., 2018) or 16L:8D and 8L:16D (Griffioen et al., 2023). Nevertheless, experimental designs and observation methods differed in these two studies. The first one investigated interactions between dietary tryptophan level and photoperiod, and activity encompassed different active behaviours over 24 h (Gomes et al., 2018). In the second study, authors observed resting behaviour and locomotion during the photophase, without an exact definition for these behaviours (Griffioen et al., 2023).

In heavy growing-finishing pigs, Martelli et al. (2015) showed that a photoperiod of 16L:8D compared to 8L:16D increased lying behaviour (lateral and sternal lying together and lateral lying only) but did not alter inactive standing, inactive sitting or locomotion in the photophase. Moreover, the posture of sows in farrowing crates was not affected by a 20L:4D or 8L:16D photoperiod (Simitzis et al., 2013).

Next to the overall activity levels, on which photoperiod seems to have a limited effect, two studies looked at activity patterns during the photophase and the scotophase when exposing pigs to different photoperiods. Lachance et al. (2010) observed higher activity during lit hours than during darkness (no statistical analysis conducted). Lay et al. (1999) found varied activity patterns between photoperiods, with weaned piglets under 24L:0D exhibiting higher activity in the evening and early in the morning than those under 12L:12D, which were in darkness during those times.

Concerning the effects of light intensity on lying behaviour, more lying pigs were observed when exposed to 5 lux than 100 lux from 48 to 60 h after being mixed with unfamiliar conspecifics at weaning (Christison, 1996). Growing-finishing pigs gradually spent more time lying in the lower intensity among a tested range of 146, 103 and 45 lux (Kim et al., 2021). Martelli et al. (2010), however, did not find differences in total lying behaviour, but they reported more lateral lying when exposed to 40 lux and more sternal lying under 80 lux. Light intensity did not affect standing and sitting postures (Martelli et al., 2010: 40 or 80 lux; Kim et al., 2021: 45, 103 or 146 lux), posture transitions in growing-finishing pigs (Kim et al., 2021) or lying posture of individually housed gilts (Canaday et al., 2013: 11 or 433 lux). When the definition of active behaviour is not only based on postures but also includes walking, feeding and drinking, the role of light intensity remains unclear as activity levels of weaned piglets exposed to 40 and 162 lux were similar (Parker et al., 2010). In addition to that, light intensities of 40 or 80 lux did not affect the locomotory behaviour of heavy growing-finishing pigs (Martelli et al., 2010).

Some studies on activity compared light treatments with variations in multiple light parameters, complicating the interpretation of individual parameters. For example, in Marinelli et al. (2020), the occurrence of standing piglets did not differ between 2 days of darkness (0L:24D) and a diurnal photoperiod (12L:12D) after postweaning mixing. However, they did not report about the intensity during the photophase, which may have played a role in this study. Opderbeck et al. (2020) reported increased lying on the solid floor when a spotlight was added above the dunging area in each pen. The result of this study, however, could be due to variations in both light intensity and spectrum. Similarly, the use of a heat lamp with visible light, as opposed to one without visible light, was associated with an increased frequency of posture changes in sows housed in farrowing crates (Liu et al., 2022). Also in this study, the effect could potentially be attributed to variations in intensity (ranging from 26 to 1 740 lux), spectrum (ambient light only or light provided by the heat lamp) and photoperiod (15L:9D from ambient light or 24L:0D from heat lamp light). Therefore, the distinct contribution of each light parameter to these results remains unclear.

In short, light affects some aspects of activity in pigs. While contradictory results make it difficult to understand exact photoperiod effects on total activity level, activity patterns are influenced by photoperiod with higher activity during lit hours. Several studies found positive associations between lower light intensities and lying behaviour, but no associations were found for other behaviours or postures.

Feeding behaviour, feed intake and drinking behaviour

Pigs' feeding behaviour is not clearly affected by light conditions. Mabry et al. (1983), for example, found higher suckling frequencies in 16L:8D than in 8L:16D for most of the observed time points (piglets of 13 days of age (**DOA**), photophase: between 400 and 500 lux). However, photoperiod did not affect the number of nursings and nursing duration in Simitzis et al. (2013) (20L:4D versus 8L:16D, photophase: 200 lux) and in Lachance et al. (2010) (23L:1D for 4 days after birth and 16L:8D thereafter versus 8L:16D, photophase: 200 lux). Exposing suckling piglets of 3 DOA to a photophase of 23L:1D shortened the interval between nursings compared to 8L:16D, but this difference was not observed when exposing them to 16L:8D or 8L:16D at 20 DOA (Lachance et al., 2010) and 20L:4D or 8L:16D (Simitzis et al., 2013). Light might still play a role, as suckling duration increased when piglets from 4 to 16 DOA were exposed to a heat lamp with white light compared to those under an unlit heat lamp (Liu et al., 2022). Yet, light treatments in this study differed in intensity, spectrum and photoperiod, thus each of these three light parameters might have impacted suckling behaviour.

In the few studies done so far, photoperiod does not seem to have a major influence on the feeding behaviour of weaned piglets and growing-finishing pigs. For example, the percentage of observed feeding behaviour did not differ between 16L:8D and 8L:16D (Griffioen et al., 2023: weaned piglets; Martelli et al., 2015: growing-finishing pigs). Inconsistent effects of photoperiod were observed in Gomes et al. (2018) with a higher percentage of pigs feeding under longer photoperiod (23L:1D compared to 12L:12D); this was reported for pigs fed with normal dietary levels of tryptophan but not for higher tryptophan levels.

Instead of observing feeding behaviour, some studies reported feed intake as it is a result from feeding behaviour. Contradictory effects of photoperiod on feed intake were reported in piglets and weaned piglets, while Bruininx et al. (2002) and Simitzis et al. (2013) agreed that prolonged photoperiods increased feed intake (23L:1D versus 8L:16D and 20L:4D versus 8L:16D, respectively). However, three other studies reported that photoperiod had no impact on feed intake of weaned piglets (McGlone et al., 1988; Gomes et al., 2018; Griffioen et al., 2023). The timing of the photoperiod, either during daytime or nighttime hours, also did not affect weaned piglets' feed intake as demonstrated by Katsumata et al. (2018).

Concerning light intensity, the feeding frequency of weaned piglets was higher in 100 lux compared to 5 lux from 48 to 60 h after being mixed with unfamiliar pigs observed from scan sampling every 10 min (Christison, 1996). However, the occurrence of feeding behaviour in growing-finishing pigs was not affected by light intensities ranging from 40 to 146 lux (Martelli et al., 2010: scan sampling every 10 min; Kim et al., 2021: continuous observation).

Feed intake did not differ between light intensities of 5 and 100 lux in weaned piglets (Christison, 1996), nor between 11 and 433 lux in mature gilts (Canaday et al., 2013). Exposing heavy growing-finishing pigs to continuous darkness or 12L:12D after mixing did not alter feed intake (Marinelli et al., 2020). Concerning light spectrum, providing triphosphor light (a specific type of fluorescent light) during daytime and red light during night time compared to standard fluorescent tubes during daytime increased weaned piglets' feed intake only for the 1st week after weaning out of 4 weeks of experiment (Glatz, 2001).

Drinking behaviour of weaned piglets (Griffioen et al., 2023) and growing-finishing pigs (Martelli et al., 2015) was not influenced by photoperiods of 16L:8D or 8L:16D, and contradictory conclusions were reported regarding the effect of light intensity. In weaned piglets, Christison (1996) observed higher drinking frequencies when pigs were continuously exposed to 100 lux in comparison with 5 lux, but this was only the case from 48 to 60 h after mixing piglets out of a total period of 72 h. Despite the continuous light, weaned piglets displayed a diurnal drinking pattern under both intensities (Christison, 1996). Moreover, in growing-finishing pigs, no effect of intensity was reported for 45 lux, 103 and 146 lux (Kim et al., 2021), while Martelli et al. (2010) found a lower percentage of drinking behaviour at 80 lux compared to 40 lux.

In summary, concerning piglets, contradicting results were obtained about the effect of photoperiod on suckling behaviour. In weaned piglets and growing-finishing pigs, photoperiod had no clear effect on feeding behaviour. However, light intensity had varying effects across production stages: increasing intensity increased feeding behaviour for a limited period after mixing weaned piglets, but had no effect on feeding behaviour in stable groups of growing-finishing pigs. A few studies found that longer photoperiods were associated with increased feed intake, yet some contradicting results were reported, and light intensity did not affect feed intake. A few studies explored light in relation to drinking behaviour, but no effect of photoperiod was observed. Increasing light intensity gave opposing results depending on whether the animals observed were weaned piglets or growing-finishing pigs.

Social interactions

Providing an environment that promotes non-harmful interactions is particularly important when (re-)establishing a social hierarchy, e.g. after creating groups of unfamiliar pigs originating from different litters or pens, or when new individuals are introduced to a group. Darkness was commonly believed to reduce negative social interactions, such as aggressive behaviour; therefore, several studies have investigated the impact of light conditions on social interactions.

Exposing weaned piglets after mixing to photoperiods of 16L:8D or 8L:16D did not affect the display of aggressive interactions (no definition of aggression provided) nor the presence of associated skin lesions (Griffioen et al., 2023). Marinelli et al. (2020) exposed growing-finishing pigs to 48 h of darkness or a 12L:12D photoperiod after mixing, and even though fewer skin lesions (on middle and hind body sections) were reported for pigs in darkness on days 3, 7 and 14 after mixing, the occurrence of agonistic behaviour did not differ. The authors suggested that the absence of light after weaning did not limit negative interactions but might have altered pigs' ability to aim at their opponent, inflicting less damage.

Furthermore, Harris and Gonyou (2003) studied piglet-directed aggressive behaviour of gilts under continuous light or 12L:12D from 3 to 5 days prefarrowing until farrowing was complete in the whole room (exact duration not reported). Continuous light resulted in a lower piglet mortality due to gilt aggression, but the severity score of observed aggressive behaviour was similar in both treatments (Harris and Gonyou, 2003); therefore, this result should be interpreted with caution.

Concerning light intensity, Christison (1996) did not observe differences in fight incidence or related wound scores after mixing between 5 and 100 lux treatments. However, between familiar heavy growing-finishing pigs, more agonistic interactions and especially more head–to–head interactions were observed under 40 lux compared to 80 lux (Martelli et al., 2010). Parker et al. (2010) drew similar conclusions since weaned piglets exposed to 40 lux were more aggressive than piglets exposed to 162 lux, although this was only the case during the 1st week after being mixed. In addition, an interaction effect between light intensity and ammonia level was found on aggressive response, with increased aggression under 40 than under 162 lux when ammonia levels were at 20 parts per million, but no difference when ammonia levels were below five parts per million. Other parameters of aggression, such as the duration of aggressive bouts, submissive and benign responses to aggression, were not influenced by light intensity (Parker et al., 2010). The authors hypothesised that low light intensity and high ammonia levels could have impaired the perception of visual and olfactory social cues affecting the establishment of hierarchy after mixing.

Concerning positive social interactions, Parker et al. (2010) also found that weaned piglets could better discriminate between familiar and unfamiliar piglets when kept under 162 lux compared to 40 lux, as in a choice test, they visited a familiar piglet more than an unfamiliar one. Supporting a possible positive effect of light intensity on social interactions, Martelli et al. (2010) observed a trend for more non-agonistic interactions, e.g. nose-to-nose contacts, in growing-finishing pigs exposed to 80 lux compared to 40 lux.

In a study investigating different light sources (Glatz, 2001), aggressive behaviour was influenced by the type of light in interaction with weaned piglets' sex and the observation period (on the weaning day or 3 days later and during nighttime or daytime). It was concluded that providing a triphosphor light during the day and red light at night, compared to fluorescent light only during the day, reduced the incidence of aggressive and harmful behaviours (Glatz, 2001). However, lesions from these behaviours were in general more severe and became more severe over time for piglets under triphosphor and red light than under fluorescent light. This discrepancy could suggest that weaned piglets exposed to triphosphor and red light fought less but more intensively (Glatz, 2001). Since light treatments in this study differed in intensity, spectrum and photoperiod, no effect of a single light parameter can be identified.

To summarise, photoperiod does not seem to clearly affect the display of negative social interactions, even though it influenced consequences of such behaviour, such as skin lesions or piglet mortality due to aggression. However, light intensity seems to be a promising light parameter as some studies point in a similar direction: fewer negative social interactions were observed under higher intensities (range from 80 to 162 lux), along with trends for more positive social interactions and better social discrimination.

Other behaviours

Some studies investigated how light treatments affected behaviours such as exploration, play, manipulation, stereotypies and elimination. Increased floor exploration was reported for photoperiods of 8L:16D compared to 16L:8D (Martelli et al., 2015), while intensities ranging from 40 to 146 lux had no effect on exploration (Martelli et al., 2010; Kim et al., 2021). Photoperiod and intensity did not affect play behaviour (Griffioen et al., 2023: 16L:8D or 8D:16D; O'Connor et al., 2010: 40 or 162 lux), ear and tail manipulation (Kim et al., 2021: 45, 103 or 146 lux; Griffioen et al., 2023), and bar biting (Martelli et al., 2015: 8L:16D or 16L:8D; Martelli et al., 2010: 40 or 80 lux). Ear chewing and tail sucking, however, were affected by the type of light and observation day, showing increased manipulation under red light compared to darkness at night on the weaning day (Glatz, 2001), although light treatments in this study differed in intensity, spectrum and photoperiod. The addition of a spotlight (more intense and cool white) above the dunging area to direct elimination behaviour towards the slatted floor was investigated, but no differences in pen fouling scores were observed (Opderbeck et al., 2020).

In summary, most studies looking at the effects of light on behaviour were somehow linked to pig productivity (feeding behaviour and activity) or welfare issues (negative social interactions), but conflicting results are often reported. Limited attention has been paid to pig behaviours relevant to positive affective states, such as play, or negative affective states, such as stereotypic behaviours.

Table 2
Overview of the studies investigating the effects of different light parameters on pig biological functioning (i.e. health, hormonal secretion and productivity) at different production stages. References are numbered and cited below this table. Combinations of light parameters tested are detailed with P standing for photoperiod, I for intensity and S for spectrum.

Theme	Light parameter(s)	Production stage	Citation
Skin lesions	Photoperiod	Weaned piglets	[21]
	Intensity	Weaned piglets	[10]
	Combined parameters	Weaned piglets	[14 (P, I and S)]
		Growing-finishing pigs	[38 (P and I)]
Other health indicators	Photoperiod	Weaned piglets	[21 (diarrhoea score)]
	Intensity	Weaned piglets	[50 (diarrhoea score)]
Immune response	Photoperiod	Suckling piglets	[48, 33]
		Weaned piglets	[48, 49]
		Sows and boars	[48]
	Intensity	Growing-finishing pigs	[39]
		Sows and boars	[9]
Vitamin D synthesis	Ultraviolet B	Suckling piglets	[58]
		Growing-finishing pigs	[1, 27, 31, 6, 47]
		Sows and boars	[58, 53]
Cortisol secretion	Photoperiod	Suckling piglets	[48]
		Weaned piglets	[49, 15]
		Sows and boars	[28, 45, 48]
	Intensity	Weaned piglets	[50]
		Growing-finishing pigs	[22]
		Sows and boars	[9]
	Combined parameters	Suckling piglets	[35 (P, I and S)]
		Weaned piglets	[2 (P, I and S)]
Melatonin secretion	Photoperiod	Growing-finishing pigs	[55, 61]
		Sows and boars	[45, 12, 19, 29]
	Intensity	Growing-finishing pigs	[22, 60]
	Combined parameters	Weaned piglets	[2 (P, I and S)]
		Sows and boars	[13 (P, I and S), 34 (P and I), 35 (P, I and S)]
Growth	Photoperiod	Suckling piglets	[36, 37, 16, 56, 48, 49, 29, 57, 41]
		Weaned piglets	[41, 8, 15, 25, 21]
		Growing-finishing pigs	[20, 42, 44, 43, 40]
		Sows and boars	[20]
	Intensity	Suckling piglets	[46]
		Weaned piglets	[10, 50]
		Growing-finishing pigs	[39]
		Sows and boars	[3, 9]
	Ultraviolet B	Suckling piglets	[58, 53]
		Growing-finishing pigs	[1, 27, 31, 6, 47]
	Combined parameters	Suckling piglets	[30 (I and S), 35 (P, I and S)]
		Weaned piglets	[14 (P, I and S)]
		Growing-finishing pigs	[38 (P and I)]
		Sows and boars	[7 (P, I and S), 24 (P, I and S), 63 (I and S), 11 (P, I and S)]
Feed efficiency	Photoperiod	Weaned piglets	[41, 8, 15, 25, 21]
		Growing-finishing pigs	[40]
	Intensity	Weaned piglets	[50]
		Growing-finishing pigs	[39]
	Combined parameters	Weaned piglets	[14 (P, I and S)]
		Growing-finishing pigs	[38 (P and I)]
		Sows and boars	[7 (P, I and S), 24 (P, I and S), 63 (I and S), 11 (P, I and S)]

1 (Alexander et al., 2017), 2 (Andersson et al., 2000), 3 (Awotwi and Anderson, 1985), 6 (Barnkob et al., 2019), 7 (Berger et al., 1980), 8 (Bruininx et al., 2002), 9 (Canaday et al., 2013), 10 (Christison, 1996), 11 (Diekman and Hoagland, 1983), 12 (Diekman et al., 1992), 13 (Diekman and Green, 1997), 14 (Glatz, 2001), 15 (Gomes et al., 2018), 16 (Gooneratne and Thacker, 1990), 19 (Green et al., 1996), 20 (Greenberg and Mahone, 1981), 21 (Griffioen et al., 2023), 22 (Griffith and Minton, 1991), 24 (Hoagland and Diekman, 1982), 25 (Katsumata et al., 2018), 27 (Kolp et al., 2017), 28 (Kraeling et al., 1983), 29 (Lachance et al., 2010), 30 (Larsen and Pedersen, 2015), 31 (Larson-Meyer et al., 2017), 33 (Lessard et al., 2012), 34 (Lewczuk and Przybylska-Gornowicz, 2000), 35 (Liu et al., 2022), 36 (Mabry et al., 1982), 37 (Mabry et al., 1983), 38 (Marinelli et al., 2020), 39 (Martelli et al., 2010), 40 (Martelli et al., 2015), 41 (McGlone et al., 1988), 42 (Minton et al., 1985), 43 (Minton and Wettemann, 1987), 44 (Minton and Wettemann, 1988), 45 (Minton et al., 1989), 46 (Morello et al., 2019), 47 (Neill et al., 2023), 48 (Niekamp et al., 2006), 49 (Niekamp et al., 2007), 50 (O'Connor et al., 2010), 53 (Panisson et al., 2021), 55 (Paterson et al., 1992), 56 (Prunier et al., 1994), 57 (Simitzis et al., 2013), 58 (Jakobsen et al., 2020), 60 (Tast et al., 2001a), 61 (Tast et al., 2001b), 63 (Wheelhouse and Hacker, 1982).

Health

Proper physiological functioning, including good health, is an important component of welfare. A couple of studies explored whether light could influence aspects of pigs' health by studying clinical health, immune response and vitamin D synthesis. A few aspects of weaned piglets' clinical health have been investigated in relation to light. Weaned piglets exposed to a longer photoperiod (16L:8D versus 8L:16D) had worse faecal consistency scores on four out of the ten observation days (Griffioen et al., 2023), while light intensity did not alter the occurrence of diarrhoea (O'Connor et al., 2010). Furthermore, no effect of photoperiod was observed on ear lesions, tail lesions and abdominal distention (Griffioen et al., 2023), and no effect of light intensity was found on lameness, ocular, nasal discharge and respiratory difficulties (O'Connor et al., 2010).

Studies on the immune system showed that a photoperiod of 23L:1D lowered the primary and secondary response of immunoglobulin G in piglets' blood compared to a photoperiod of 8L:16D (Lessard et al., 2012). Similar lower blood immunoglobulin G was found for weaned piglets from 8 to 10 weeks of age exposed to 16L:8D compared to 8L:16D, but it was only the case for piglets weaned at 21 DOA and not for piglets weaned at 14 or 28 DOA (Niekamp et al., 2007). Blood immunoglobulin G levels of gestating sows exposed to 8L:16D or 16L:8D did not differ (Niekamp et al., 2006).

The neutrophil concentration in blood, a sign of infection, disease or tissue damage, did not differ between photoperiods of 16L:8D and 8L:16D in piglets before weaning (at 7 and 21 DOA) (Niekamp et al., 2006). When measured after weaning (from 8 to 10 weeks of age), no difference was reported between 16L:8D and 8L:16D for piglets weaned at 14 and 28 DOA, but higher neutrophil percentages were observed in the longer photoperiod for piglets weaned at 21 DOA (Niekamp et al., 2007).

Effects of photoperiod on blood lymphocytes concentrations show contradictory results between days of sampling (Lessard et al., 2012), age at weaning (Niekamp et al., 2007) and sex (Niekamp et al., 2006). Consequently, the blood neutrophil to lymphocyte ratio, used as an early marker of disease or stress, seems only slightly influenced by photoperiod. A better response with a lower ratio, due to lower neutrophils, was found for 6-week-old piglets weaned at 21 days when exposed to 8L:16D compared to 16L:8D (Niekamp et al., 2007), whereas photoperiod did not affect the neutrophil to lymphocyte ratio of 8– and 10-week-old weaned piglets (Niekamp et al., 2007) and sows (Niekamp et al., 2006).

Photoperiod had no effect on the percentage of neutrophil phagocytosis (a sign of pathogen recognition and ingestion by immune cells) in blood of sows exposed to 8L:16D or 16L:8D for 7 weeks. A longer photoperiod, however, enhanced neutrophil phagocytosis in 21-day-old piglets under 16L:8D compared to 8L:16D (Niekamp et al., 2006). Moreover, phagocytosis activity in piglets of 23 DOA was enhanced under 16L:8D compared to 8L:16D (Lessard et al., 2012). In contrary, a longer photoperiod reduced neutrophil phagocytosis in piglets of 8 and 10 weeks of age weaned at 14 and 28 DOA and exposed to 16L:8D compared to 8L:16D (Niekamp et al., 2007). Niekamp et al. (2006) also measured the proliferation index of concanavalin A (**ConA**, an antigen) and lipopolysaccharides (a stimulant of immune cells) and observed lower ConA proliferation under 8L:16D than 16L:8D for sows during the farrowing phase, indicating a lower immune response. No consistent photoperiod effect was observed on ConA proliferation during gestation or on lipopolysaccharide proliferation during both gestation and farrowing phases. Nevertheless, for their 21-day-old piglets, an 8L:16D photoperiod led to higher proliferation of both ConA and lipopolysaccharides (Niekamp et al., 2006), indicating a better immune response.

Light intensity seems to have a limited effect on immune functioning as only the eosinophil percentage was higher in gilts exposed to 11 lux compared to 433 lux (Canaday et al., 2013), suggesting an increased immune response under the lowest intensity. This light parameter had no influence on phagocytosis, proliferation indexes of ConA and lipopolysaccharides, counts and percentages of neutrophils, lymphocyte and monocytes, and neutrophil to lymphocyte ratio (Martelli et al., 2010; Canaday et al., 2013).

Regarding the vitamin D status of pigs, providing direct daylight increases serum vitamin D_3 contents via the cutaneous synthesis. One hour per day of daylight exposure for 2 weeks in spring, summer and autumn months was sufficient to elevate serum vitamin D_3 contents in growing-finishing pigs compared to indoor housing without any access to daylight (Alexander et al., 2017). Synthesis was further increased when pigs were exposed daily to daylight for 1 h in spring-summer compared to summer-autumn over 2 weeks (Larson-Meyer et al., 2017). Alexander et al. (2017) showed that pigs had a peak of serum vitamin D_3 during the first 24 h after exposure to daylight followed by a decrease from 40 h postexposure that stabilised after 4 weeks postexposure. Vitamin D_3 and vitamin D_3 metabolites were highest in tissues such as loin and subcutaneous adipose tissue in daylight-exposed pigs (Larson-Meyer et al., 2017). Panisson et al. (2021) explored the interaction between providing vitamin D_3 in sows' feed and housing systems with or without daylight. The interaction between dietary provision of vitamin D_3 and daylight exposure was significant, and while in absolute numbers, levels of serum vitamin D_3 were higher in sows receiving daylight, no significant differences were reported. Many aspects related to housing differed in this experiment (e.g. individual stalls or group-housed pens, feeding system, light conditions), which might have interfered with daylight effects.

Additionally, a few recent studies explored the effect of providing UVB radiation through artificial lighting on the cutaneous synthesis of vitamin D_3. Consistent with daylight exposure, elevated levels of vitamin D_3 were observed in UVB-irradiated sows (Jakobsen et al., 2020), suckling piglets (Jakobsen et al., 2020) and growing-finishing pigs (Kolp et al., 2017; Barnkob et al., 2019; Neill et al., 2023). Providing artificial UVB radiation effectively increased the content of vitamin D_3 and/or vitamin D_3 metabolites in serum (Jakobsen et al., 2020), muscle tissue (Neill et al., 2023), adipose tissue and organs (Barnkob et al., 2019). In addition, a positive correlation was found between vitamin D_3 content in serum (considered as the gold-standard) and vitamin D_3 content in tissues such as rind, subcutaneous fat, lean meat and liver, and therefore, serum vitamin D_3 was suggested as a good indicator to assess vitamin D_3 levels in pork products (Barnkob et al., 2019).

The dose of UV provided seems to matter for vitamin D_3 synthesis. While Jakobsen et al. (2020) did not report differences in serum vitamin D_3 between 0.7 and 1 SED, Barnkob et al. (2019) observed increased contents in all sampled tissues and organs in 1 SED compared to 0.7 SED. When keeping the UV dose equal, the duration of the exposure also seems to play a role in the location where vitamin D_3 is synthesised and stored. The increase in loin vitamin D_3 was only observed when 1 SED was provided for 6 min instead of 2 min, thus longer exposure duration was suggested to allow pigs to stand and thereby be closer to the UV source resulting in more vitamin D_3 stored in loin (Neill et al., 2023). In addition, a progressive habituation to UV is an important aspect to consider since increasing the UV dose from 0 to 2 SED in 8 days induced mild erythema (sunburn) in pigs (Barnkob et al., 2019).

A deficiency of vitamin D_3 hampers intestinal calcium absorption and increases parathyroid hormone in circulation, causing bone demineralisation through the release of calcium from bones (Holick, 2011). In pigs, only one study included bone-related measures in relation to UV exposure; however, authors did not find clear effects on bone mineral content and density, bone formation or bone turnover biomarkers (Kolp et al., 2017).

In short, it remains unclear whether photoperiod and light intensity affect pigs' health parameters. However, in the few studies done so far, photoperiod seems to affect the immune system, though findings are inconclusive across studies, while light intensity shows no effect on pig immune responses. Exposure to daylight led to higher blood vitamin D_3 contents regardless of the season, though no studies were conducted in winter. It was reported that 24 h after exposure to daylight, blood vitamin D_3 content dropped and remained constant from 4 weeks postexposure onwards, and higher levels vitamin D_3 metabolites were stored in muscle and adipose tissues of daylight-exposed animals. Artificial UVB provision also increased the vitamin D_3 content in blood, diverse tissues and organs. There seems to be a positive relationship between UV dose and vitamin D_3 synthesis. However, the exposure duration influences vitamin D storage in some tissues and habituation to UV exposure should be considered to avoid the occurrence of sunburn.

Hormonal secretions

The hypothalamic–pituitary–adrenal axis is responsible for adapting the stress response through hormonal secretion, but also for regulating other circadian hormonal secretion patterns (Larzul et al., 2015). A hormone commonly used as a stress marker in pigs is cortisol and several studies investigated how light conditions affect cortisol levels.

Minton et al. (1989), for example, demonstrated that the timing of light onset (either at 0200 or 0800 h with an equal photoperiod of 16L:8D) shifted the cortisol secretion pattern of prepubertal boars according to the lit period, whereby the peak levels of cortisol were observed 1–2 h before the scotophase onset (Minton et al., 1989).

During gestation, Niekamp et al. (2006) exposed sows to a long (16L:8D) or a short photoperiod (8L:16D) and at farrowing, these sows and their piglets either stayed under the same photoperiod (long or short) or changed to the other photoperiod (from long to short or vice versa). At 7 DOA, piglets from sows exposed first to a long photoperiod (gestation) and then to a short photoperiod (farrowing) presented higher cortisol levels compared to piglets experiencing first a short (gestation) and then a long photoperiod (farrowing), and to piglets receiving continuously the same photoperiod (either long or short during gestation and farrowing) (Niekamp et al., 2006). At 21 DOA, no difference in cortisol levels was found anymore between all photoperiod combinations. Furthermore, these combinations of photoperiods during gestation and farrowing did not affect sows' cortisol levels when measured 7 days or 21 days postpartum (Niekamp et al., 2006). However, in another study, lactating sows that had farrowed during autumn and were exposed to daylight until 10 days before farrowing showed higher postfarrowing levels of cortisol with a 16L:8D photoperiod than with an 8L:16D photoperiod (Kraeling et al., 1983). No differences in cortisol levels between photoperiod treatments were observed for sows that had farrowed in summer (Kraeling et al., 1983).

In 6– to 10-week-old weaned piglets, a significant interaction effect of photoperiod by age at weaning was found, but cortisol levels of piglets exposed to 16L:8D or 8L:16D did not differ for any of the weaning ages tested (at 14, 21 or 28 days old) (Niekamp et al., 2007). Providing a photoperiod of about 17L:7D via daylight supplemented with artificial light increased cortisol levels of weaned piglets compared to the same photoperiod under artificial light only or an artificial photoperiod shorter than daylight (about 8L:16D) (Andersson et al., 2000). However, as the light source differed, photoperiod only might not explain this result as treatments also differed in intensity and spectrum due to the presence of daylight. Lastly, Gomes et al. (2018) studied the effect of photoperiod on weaned piglets' cortisol secretion, and hypothesised that dietary tryptophan could be involved in the secretion of serotonin influencing cortisol levels. Contradictory effects of photoperiod were found, with normal tryptophan levels, the longer photoperiod (23L:1D) increased cortisol concentrations compared to the shorter photoperiod (12L:12D), while inverse results were obtained with high tryptophan levels.

The effect of light intensity on cortisol secretion seems much more limited than the effect of photoperiod, as cortisol levels did not differ in gestating gilts exposed to 11 or 433 lux for 12L:12D (Canaday et al., 2013), or in male growing-finishing pigs exposed to continuous darkness or continuous light (202 lux) (Griffith and Minton, 1991). Circadian patterns of cortisol secretion were also maintained in continuous darkness and under continuous light, even though more individual variation was observed in pigs exposed to 202 lux (Griffith and Minton, 1991). When cortisol levels were measured during a stress reactivity trial involving social isolation of weaned piglets exposed to 40 or 200 lux, no effect of light intensity was found on cortisol levels (O'Connor et al., 2010). An interaction between light intensity and ammonia levels was found for baseline cortisol concentrations in weaned piglets, but cortisol concentration did not differ between light intensities for any of the ammonia levels tested (O'Connor et al., 2010).

One study investigated the effect of heat lamps with different light sources on piglet cortisol levels, but no clear trend was observed as cortisol levels were higher at only one of the four time points in piglets exposed to heat lamps without light compared to piglets exposed to heat lamps with IR and red light (Liu et al., 2022).

Melatonin is a hormone secreted in darkness, and light is known to inhibit its release. Therefore, several studies focused on the action of light on the secretion of melatonin in pigs' blood. When exposing pigs to light treatments of equal photoperiod, but differing in onset time (0200 or 0800 h), secretion patterns of both treatments were similar and no distinctive nocturnal peak of melatonin was observed with a photophase intensity of 202 lux and a scotophase intensity of 7 lux (Minton et al., 1989). These unexpected results could be explained by a high variability in melatonin concentration between individuals and between time points, and by a limited sample size of four prepubertal boars. Along the same line, but on a larger scale (24 gilts), Green et al. (1996) observed that only 56% of gilts showed a weak nocturnal elevation of melatonin levels. Including the initial melatonin level during photophase as a covariate resulted in a significantly elevated melatonin level during the scotophase compared to the photophase (Green et al., 1996). This diurnal pattern of melatonin secretion with a scotophase elevation and high individual variation was also reported in prepubertal boars by Andersson et al. (2000). Melatonin elevation before the scotophase onset was found in weaned piglets by Tast et al. (2001b) and in growing-finishing pigs as well by Paterson et al. (1992). The latter suggested that the diversity of analytical methodology could explain differences between studies.

Growing-finishing pigs' melatonin secretion patterns adapt to the duration of the photoperiod as demonstrated by Tast et al. (2001b). When the photophase was shortened and lights were off 4 h earlier than usual, they found an immediate melatonin elevation within 1 h after lights were switched off, but the adaptation of melatonin elevation to a longer photophase (with light off later than usual) was gradual over a week. In another study, gradually shortening the photoperiod from 12L:12D to 9L:15D (compared to increasing it) led to a biphasic scotophase secretion of melatonin with two nocturnal peaks separated by a drop, though the sample size in this study was limited to four pigs (Paterson et al., 1992).

Although several studies showed that photoperiod modulates melatonin patterns, there is no consensus on the impact of shorter or longer photoperiods on the overall melatonin level in pigs. For example, a lower melatonin concentration was found in sows exposed to 23L:1D compared to 8L:16D after 1 week of exposure, but no difference was found between 16L:8D and 8L:16D on the 25th day of exposure (Lachance et al., 2010). Moreover, no effect of photoperiod on melatonin concentrations was found between pigs exposed to continuous light or 9L:15D (Diekman et al., 1992), nor between pigs exposed to continuous light or 14L:10D (Lewczuk and Przybylska-Gornowicz, 2000), though both studies also had limited sample sizes of six prepubertal gilts. The timing between the exposure to a different photoperiod and the moment of sampling seems to matter as a long photoperiod altered melatonin levels after 7 days of exposure to a new light, but not later on (Lachance et al., 2010). When pigs had an adaptation phase of 1 week to 1 month before sampling, the overall levels of melatonin did not differ between photoperiods (Diekman et al., 1992; Lewczuk and Przybylska-Gornowicz, 2000). Thus, it could be hypothesised that pigs' secretion pattern of melatonin could adapt to a novel photoperiod within a week.

One study testing daylight against artificial light reported higher melatonin level during scotophase when pigs were exposed to daylight compared to artificial light (Andersson et al., 2000), yet this result can also be attributed to parameters of daylight varying in intensity and spectrum over the day compared to static light parameters from fluorescent light.

Light intensity seems to be a factor influencing the diurnal pattern of melatonin secretion in growing-finishing pigs. Two studies tested the effects of continuous light of different intensities on melatonin patterns. It seemed that a constant intensity of 500 lux was sufficient to inhibit the nocturnal elevation of melatonin in growing-finishing pigs, while a diurnal melatonin pattern was observed under a constant intensity of 1 lux (Lewczuk and Przybylska-Gornowicz, 2000), but also with constant intensities of 7 and 202 lux (Griffith and Minton, 1991). Providing a scotophase (<1 lux) was sufficient to induce the nocturnal elevation irrespective of the photophase intensity (40, 200 or 10 000 lux) in growing-finishing pigs (Tast et al., 2001a).

It is unsure if the light intensity during the photophase can modulate the overall melatonin level. According to Griffith and Minton (1991), growing-finishing pigs kept under a constant 202 lux showed higher melatonin levels than pigs under a constant 7 lux, which was against expectations. While other studies concluded that the intensity during the photophase did not affect overall melatonin concentrations (Lewczuk and Przybylska-Gornowicz, 2000, comparing continuous darkness to 500 lux; Tast et al., 2001a, comparing intensities of 40, 200 and 10 000 lux). These mixed results could be explained by the small sample sizes (4–6 pigs per treatment) coupled with a high individual variability between growing-finishing pigs, as also noticed in Tast et al. (2001a).

The effects of different light sources on melatonin secretion have also been investigated. Piglets exposed to heat lamps providing white light did not show a salivary nocturnal melatonin elevation, whereas such a rise was observed for piglets under heat lamps without light and heat lamps producing IR and red light (likely out of pigs' spectral sensitivity) (Liu et al., 2022). The melatonin secretion of prepubertal gilts exposed to daylight or artificial light, however, did not differ (Diekman and Green, 1997). No clear interpretation of light effects can be concluded as these treatments differed in photoperiod, intensity and spectrum.

To summarise, light plays a role in the secretion of cortisol with light onset related to increased cortisol secretion. Even though some inconsistencies were found in sows and piglets, longer photoperiods seem to be associated with higher cortisol levels. Moreover, no effects of light intensity were found on cortisol secretion in pigs. Photoperiod was found to affect some aspects of the melatonin secretion pattern, such as creating a contrast between daytime and nighttime melatonin levels, as well as the nocturnal elevation onset and profile. Several authors reported overall low melatonin secretion in pigs with high variability between individuals. Regardless of the light intensity, the provision of a dark period induced nocturnal melatonin elevation, while exposing pigs continuously to 500 lux blocked this nocturnal elevation found in circadian melatonin secretion patterns.

Productivity

The main light parameter investigated in relation to productivity is photoperiod. Studies about the effects of photoperiod on pigs' growth have covered different production stages. Four studies found that longer photoperiods were associated with higher growth and final weight in suckling piglets, when comparing photoperiods of 16L:8D with 8L:16D (Mabry et al., 1982; Mabry et al., 1983: 21 DOA; Niekamp et al., 2007: from 14 to 28 DOA) or 20L:4D with 8L:16D (Simitzis et al., 2013: 28 DOA). However, four other studies in suckling piglets did not observe this difference with similar photoperiods (Gooneratne and Thacker, 1990; Niekamp et al., 2006: 21 DOA), longer photoperiods (Lachance et al., 2010: 23 DOA), decreasing or increasing photoperiods (Prunier et al., 1994: 21 DOA). Reasons for these conflicting results could be a different setup with variable photoperiods over time and a less clear contrast between treatments at the beginning of the experiment in Prunier et al. (1994), or a possible interaction effect not reported between tested photoperiods and the provision of creep feed (provided or not) in Gooneratne and Thacker (1990). A major limitation to some of these studies is that piglets were not weighed at birth and only weaning weights were compared between photoperiods, therefore, unbalanced birth weights may have influenced piglets' growth and have led to incorrect conclusions (Mabry et al., 1982, 1983; Gooneratne and Thacker, 1990; Lachance et al., 2010; Simitzis et al., 2013).

In weaned piglets and growing-finishing pigs, the effects of photoperiod on growth are inconclusive as two studies reported an increase of average daily gain for pigs exposed to longer photoperiods e.g. 23L:1D compared to 8L:16D (Bruininx et al., 2002) and 16L:8D compared to 8L:16D (Martelli et al., 2015), but these differences were only reported for specific periods of the experiment. Two other studies reported trends for lower average daily gain in longer photoperiods (16L:8D versus 8L:16D in Griffioen et al., 2023) or lower weights for pigs exposed to longer photoperiods at different timepoints (15L:9D versus 8L:16D in Greenberg and Mahone, 1981). Moreover, several studies did not report any effect of photoperiod on the weight gain of weaned piglets (McGlone et al., 1988; Gomes et al., 2018) and growing-finishing pigs (Minton et al., 1985; Minton and Wettemann, 1988). In three of these studies, it was not mentioned if pigs were isolated from daylight, which is important because daylight could have interfered with the photoperiod treatments (Minton et al., 1985; McGlone et al., 1988; Gomes et al., 2018). Furthermore, in climate-controlled chambers, Katsumata et al. (2018) found no impact of the onset of photoperiod during either daytime hours or nighttime hours on the weight gain of weaned piglets. It is unlikely that the intensity of tested photoperiods explains these inconsistencies, as light intensities in studies reporting effects of photoperiod on growth ranged from 40 to 500 lux, while intensities in studies not reporting any effects ranged from 100 to 650 lux.

In line with this hypothesis, light intensities ranging from darkness (0 lux) to 433 lux did not influence the growth of suckling piglets (Morello et al., 2019: 28 DOA), weaned piglets (Christison, 1996; O'Connor et al., 2010), growing-finishing pigs (Martelli et al., 2010) and mature gilts (Awotwi and Anderson, 1985; Canaday et al., 2013). Furthermore, providing daylight, containing UV radiation, or providing UVB with an artificial light source did not affect growth in piglets (Jakobsen et al., 2020; Panisson et al., 2021) and growing-finishing pigs (Alexander et al., 2017; Kolp et al., 2017; Larson-Meyer et al., 2017; Barnkob et al., 2019; Neill et al., 2023).

As mentioned in previous sections, some experiments investigated combinations of three light parameters simultaneously; for example, Larsen and Pedersen (2015) and Liu et al. (2022) compared heat lamps with different light sources to heat lamps not providing light, Berger et al. (1980), Hoagland and Diekman (1982) and Diekman and Hoagland (1983) tested the supplementation of daylight with artificial light, and Glatz (2001) compared diurnal fluorescent tubes to triphosphor light during daytime with invisible red light at nighttime. Yet, none of the tested combinations significantly affected growth. Likewise, different photoperiod-intensity combinations (Marinelli et al., 2020: continuous darkness versus light for 12L:12D, intensity not reported) and intensity-spectrum combinations (Wheelhouse and Hacker, 1982: cool white light of 500 lux, daylight-like of 650 lux, red of 65 lux and UV of 65 lux) did not affect growth.

The combination of feed intake and growth is captured in feed efficiency, which is relevant for pig productivity. In several studies that investigated the effects of photoperiod on feed efficiency, no significant effect was found, e.g. for suckling piglets (McGlone et al., 1988: 28 DOA) and weaned piglets (Bruininx et al., 2002; Griffioen et al., 2023). Two studies, however, reported different results; in Gomes et al. (2018), shorter 12L:12D photoperiods led to a 6% lower feed conversion ratio compared to 23L:1D during the first 14 days after weaning, but not in the 14 days thereafter. In Martelli et al. (2015), a 10% lower feed conversion ratio was found for a longer photoperiod (16L:8D versus 8L:16D) over the first 5 months of the growing-finishing phase of pigs raised for Parma ham production. Inverting the photoperiod with lit time at night and dark time during the day did not influence the feed efficiency of weaned piglets (Katsumata et al., 2018).

In terms of light intensity, levels ranging from 38 to 172 lux had no effect on feed conversion ratios in weaned piglets (O'Connor et al., 2010) and growing-finishing pigs (Martelli et al., 2010). Furthermore, experiments altering several light parameters at the same time did not impact feed efficiency; whether they supplemented daylight with artificial light in prepubertal pigs (Berger et al., 1980; Hoagland and Diekman, 1982; Diekman and Hoagland, 1983), provided diurnal light conditions or darkness after mixing growing-finishing pigs (Marinelli et al., 2020), or tested different light types (Wheelhouse and Hacker, 1982: prepubertal gilts; Glatz, 2001: weaned piglets).

In short, light in relation to pig productivity has been quite extensively studied, especially for growth performance. Photoperiod seems to be a light parameter that could influence the growth of suckling piglets. However, this was not as clearly reported in weaned piglets and growing-finishing pigs with either no significant effect of photoperiod found or photoperiod effects found for a limited period only. Light intensity and different combinations of several light parameters together do not seem to affect pig growth, but the effects of light spectrum remain unknown because this light parameter alone has never been studied. Overall, the effects of light on growth are limited, the effects of light on feed intake are inconsistent and consequently, feed efficiency did not appear to be strongly influenced by light conditions.

Discussion

Limitations in the literature

In reviewing the existing literature about the effects of light on pigs, the principal light parameter investigated was the photoperiod, representing 44% of the papers in the dataset. Less studies looked into the intensity of light (21%) and few papers studied light spectrum (3% on visible light and 11% on UV). The remaining papers (21%) tested light treatments that varied in more than one light parameter at once and although those papers could indicate interactions between combinations of light parameters, more knowledge on the role of overlooked individual light parameters such as light spectrum and, to a lesser extent, light intensity would help to identify important light conditions for pigs. There is a critical knowledge gap on the effects of light spectrum since it has only been individually investigated in a preference test (Fig. 3 and Table 1). Interactions in light parameters were sometimes tested intentionally, for example, when comparing two light sources differing in both light spectrum and intensity (Liu et al., 2022). However, in some other cases, these interactions in designed light treatments were not considered at all, and conclusions may have been incorrectly made on one single light parameter. For instance, studies tested the supplementation of daylight with artificial light to increase the photoperiod (e.g. Hoagland and Diekman, 1982), but these treatments were not comparable in light intensity and spectrum.

A limitation found in many studies is the scarce amount of information on light conditions. The presence or absence of daylight was often not reported and it is therefore unclear whether the conclusions drawn on the tested light parameter were influenced by daylight. Besides the presence of daylight, several studies did not report other light parameters than the one(s) of interest. Information on light intensity was lacking occasionally, but information on light spectrum was missing the most (84% of the papers). Moreover, it has been suggested by Tanida et al. (1996) and Taylor et al. (2006) that pigs may prefer light treatments closest to the conditions experienced prior to the start of the experiment. Therefore, pre-experimental light conditions may have a carry-over effect and influence pigs' response to a new light treatment. In addition, in photoperiod studies, results may be affected by pigs inadvertently experiencing increasing or decreasing photoperiods when changing from pre-experimental to experimental conditions, rather than by the tested photoperiod contrast. However, this information was lacking in most of the papers found, but might have contributed to some variation in the results.

Next to the limited amount of information reported to characterise light treatments (e.g. light spectrum), methods used to measure light parameters lacked consistency and this holds especially for light intensity. A factor influencing the reading of a light intensity measurement is the distance between the light source and the measurement point. It is therefore important to indicate the measurement height and if the reported value results from one point below the light source or from a mean of several measurements in a pen that could account for within−pen variability. In reviewed papers, light intensity measurements were often performed at a height corresponding approximately to pigs' eyes height for the investigated production stage (63% of the papers, ranging from 30 cm to 60 cm), which is a biologically relevant measurement. However, the location of measurements to the light source is rarely reported (16% of the papers), making the comparison between studies difficult. First, establishing guidelines to standardise light measurement methods could help to make future studies more comparable. Second, legislation does not provide any recommendation on how to measure light conditions on farm (height or position related to the light sources) and this lack of information makes the implementation of the minimum requirements more questionable in practice.

Literature reporting the effect of light on pigs differs in the level of control pigs have on their environment, e.g. the possibility to choose between certain light conditions in preference tests versus fixed light treatments applied in commercial housing conditions. In some cases, preference studies suggested that light parameters may play a role in the display of behaviours. For instance, pigs preferred to display elimination behaviour under higher light intensities or cooler light colour temperatures (Taylor et al., 2006; Götz et al., 2020). Such findings could not always be confirmed when light treatments were applied to commercial housing conditions (Opderbeck et al., 2020). This suggests that results from preference studies are not always applicable in commercial housing conditions, where creating clear contrasts of intensity or spectrum within a pen may be more difficult due to limited available space.

Existing literature mainly investigated the influence of light on the productivity, physiology and behaviour of pigs but the quality of darkness has received very little attention as suggested by Taylor (2010). In a preference study on light intensity, two chambers had intensities of 2.4 and 4 lux and weaned piglets showed a preference to rest in the darkest chamber compared to the intensity of 4 lux (Taylor et al., 2006). This suggests that pigs were able to distinguish between these two dim environments, and darkness (maximum light intensity during the scotophase) could be a relevant aspect to investigate in relation to pig welfare and may need more attention in legislation.

Method of the systematic approach

The objective of the systematic review was to summarise current literature about the effects of light on pig welfare. A challenge in the identification of papers to include in this systematic review was related to the two main keywords, pig and light, which are general terms that can have different meanings. For instance, "pig" retrieved articles related to a light converter called phosphor-in-glass abbreviated, and "light" retrieved many records using analytical methods involving light on all sorts of pig products, such as light microscopy on sow milk. In combination, a substantial amount of papers consisted of experiments on pigs with light BW, thus exclusion terms were added to the search string to filter out a large amount of irrelevant papers. This step may have discarded potentially relevant papers and might explain why a substantial number of papers have been retrieved during the snowballing step (16 papers).

Furthermore, during the screening process, a large proportion of the papers was discarded because light treatments were not compared simultaneously (46 papers in the first screening and 6 in the screening after snowballing). Often these papers investigated the effect of increasing or decreasing photoperiod provided by daylight by collecting data during spring-summer for one treatment and during summer-autumn for the other. In that case, many non-light related factors (e.g. environmental conditions) might have been falsely interpreted as treatment effects, and therefore, this kind of longitudinal studies with possible confounding factors were excluded from the dataset.

Current research gaps

In the past, most of light studies in pigs focused on productivity, and for the last 20 years, a few studies investigated the effect of light on some welfare aspects, however, several knowledge gaps still remain. In animal welfare, there is an increasing interest in taking affective states into account as proposed by Fraser (2008) and Mellor (2016). In humans, light therapy is sometimes used to alleviate conditions such as seasonal and non−seasonal affective disorders (Terman, 2007). In pigs, only four studies have measured the impact of light on behaviours that can be associated with a positive affective state, like play behaviour, or a negative affective state such as tail and ear biting behaviour. Nonetheless, none of the studies reported these behaviours in relation to affective states. Further work is needed to understand the effects of light on the affective states of pigs and ultimately on their welfare by, for example, studying behaviours that could reflect positive or negative affect.

In recent years, more attention has been paid to the impact of providing UV light on the vitamin D_3 status of pigs. The studies presented thus far provide evidence that pigs synthesise and store vitamin D_3 in tissues when exposed to UV from daylight or artificial light. While the role of vitamin D_3 in human health and welfare is better known (e.g. positive effects on bone, immunity, cardiovascular disease and mood disorders), the consequences of improved vitamin D_3 status on pig health are not extensively described (2% of the papers focussing on bone mineralisation) and the effects on overall pig welfare remain unknown. Thus, a more comprehensive assessment of pig welfare (including e.g. bone mineralisation, immunological biomarkers or affect) could be performed in future studies on UV light.

It is interesting to mention that two studies compared the effect of providing daylight (through outdoor access) with exposure to artificial light (in indoor housing) on specific physiological aspects. Concerning the secretion of melatonin, no difference was found between indoor and outdoor-housed pigs (Diekman and Green, 1997). However, exposure to daylight increased vitamin D_3 synthesis (Panisson et al., 2021). Until now, no studies have investigated if providing daylight (directly or through windows) is beneficial for pig welfare in comparison to artificial lighting. Such studies with equal housing conditions might be challenging to set up, but could indicate if developing future artificial light technologies to mimic daylight might benefit pig welfare.

Research to date has mainly investigated light sources that are currently either banned or in the process of being banned in some countries. In Europe, this is the case for incandescent lights since 2009, for halogen lights since 2018 and more recently in 2023 for fluorescent lights. The purpose of these regulations is to promote a switch to more energy-efficient and environmentally friendly lights, such as LED lights. However, very little is known about the use of LED lights in pig housing since only 10% of the reviewed papers used this light source. Furthermore, LED lights offer flexibility as all light parameters (photoperiod, light intensity and spectrum) can be tuned. If providing variations in light over the day and between days (similar to daylight exposure) is found to be beneficial for pigs, tuning LED light to mimic daylight may be considered as a more effective alternative to daylight, since daylight exposure can cause heat stress and provides heterogeneous illumination in barns (e.g. bright light close to windows and dim light far from windows). Furthermore, mimicking daylight with LED could be an alternative to conventional light sources in high−latitude countries subjected to long and dark winters.

Conclusion

Light in pig housing has mainly been investigated in relation to pig productivity. In the reviewed studies, photoperiod is the only light parameter that affected growth and to a lesser extent feed intake, but conflicting results are reported so it remains unclear whether photoperiod can improve pig productivity. Moreover, the effects of both photoperiod and light intensity on feeding and drinking behaviour are inconsistent.

Nevertheless, pigs seem to rest more in darker environments and consequently show more elimination behaviour in brighter environments. Activity patterns of domestic pigs follow the photophase provided, with increased activity during lit hours. While photoperiod does not clearly affect social interactions, slightly increased light intensity after weaning shows the potential to limit negative social interactions, promote positive interactions and improve social discrimination. Concerning physiological parameters, the secretion pattern of cortisol and melatonin are affected by light with light onset increasing cortisol levels and the contrast between the photophase and the scotophase inducing nocturnal elevation of melatonin. Moreover, exposure to UV can improve the vitamin D_3 status of pigs. However, the impact of both photoperiod and light intensity on the immune system remains ambiguous.

Future research should investigate light parameters and light sources that have been overlooked as very little is known about the effects of light spectrum or LED lights on pig welfare. Current research in this field covered specific aspects of pig welfare; however, more research is needed to investigate the effects of light parameters on pig welfare as a whole, including affective states.

Supplementary material

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Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository. Information can be made available from the authors upon request.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

Author ORCIDs

A.J. Scaillierez: https://orcid.org/0000-0002-2586-5882.
S.E. van Nieuwamerongen - de Koning: https://orcid.org/0000-0002-6368-4855.
I.J.M.M. Boumans: https://orcid.org/0000-0002-9927-089X.
P.P.J. van der Tol: https://orcid.org/0000-0002-6531-3628E.
E.A.M. Bokkers: https://orcid.org/0000-0002-2000-7600.

CRediT authorship contribution statement

A.J. Scaillierez: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **S.E. van Nieuwamerongen - de Koning:** Writing – review & editing, Methodology, Investigation, Conceptualization. **I.J.M.M. Boumans:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **P.P.J. van der Tol:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **E.A.M. Bokkers:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of interest

None.

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