French Reference Centre
for Animal Welfare

OPINION

Impacts of loading density on the risk of falls and injuries in pigs during transport

Original title in French

Impacts de la densité de chargement sur le risque de chutes et de blessures des porcs pendant le transport

JANUARY 2026

French Reference Centre for Animal Welfare

Impacts of loading density on the risk of falls and injuries in pigs during transport

Requested by
Animal Welfare Office (BBEA) of the General Directorate for Food (DGAL), French Ministry of Agriculture and Food Sovereignty

Date of request
28/08/2024

Date delivered by the FRCAW
23/05/2025

Date of most recent version in French
17/09/2025

Date of publication in English
30/01/2026

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Suggested citation for the English version

Violaine Colson, Camille Bezançon, Louise Kremer, Lisa Diaz, Agnès Tiret, CNR BEA experts, Geneviève Aubin-Houzelstein. Opinion of the FRCAW on the impacts of loading density on the risk of falls and injuries in pigs during transport. FRCAW / CNR BEA. 2025. Translated by Teresa Bridgeman

DOI: doi.org/10.17180/2g18-p251

Suggested citation for the original report in French

Violaine Colson, Camille Bezançon, Louise Kremer, Lisa Diaz, Agnès Tiret, Experts du CNR BEA, Geneviève Aubin-Houzelstein. Avis du CNR BEA sur les impacts de la densité de transport sur le risque de chutes et de blessures pour les porcs. CNR BEA. 2025.

DOI: 10.17180/8ogw-26lp

Summary

In 2023, a proposal for a regulation on the protection of animals during transport repealing Council Regulation (EC) No 1/2005 was published. The new text proposes a revision of the rules on space allowances based on the recommendations of the EFSA opinion on the welfare of pigs during transport (EFSA, 2022). The present report from the French Reference Centre for Animal Welfare (FRCAW) summarises the key points of the EFSA opinion (2022), focusing mainly on information relating to falls and injuries associated with loading density during transport. In addition, it provides an in-depth analysis of the literature on the subject, examining the consequences of different loading densities/space allowances on various welfare indicators including not only behaviour and physiology but also mortality and carcass quality. The report also highlights the factors that can lead to falls and injuries in pigs during transport, and suggests ways to reduce their incidence. Although very few existing studies have looked at pig falls and injuries at the space allowances for transport set out in the regulatory proposal, none indicate that the new densities would increase these risks. Of the four studies that compared the precise current regulatory space allowance (≥ 0.42m^2/100kg pig) with allowances close to that proposed in the new regulation (≥ 0.58m^2/100kg pig), only one assessed the impact of the space allowance on injuries, concluding that the higher allowance was associated with a reduction in the occurrence of haematomas. Another study investigated aggressive behaviour in pigs, observing a reduction in the duration of fights with the higher space allowance. Nevertheless, further studies are needed to confirm these results and to elucidate the specific effects of transport, taking into account the potential aggravating factors considered in this report.

Keywords

Transport / Loading density / Falls / Injuries / Pigs

> VIEW ALL WORK CARRIED OUT BY THE FRCAW

Context

The European regulations on farm animal welfare are currently under review. In December 2023, the European Commission published its Proposal for a Regulation of the European Parliament and of the Council on the protection of animals during transport and related operations, amending Council Regulation (EC) No 1255/97 and repealing Council Regulation (EC) No 1/2005, currently in force. This revision was initiated in order to bring the regulatory requirements into line with new scientific knowledge on animal welfare during transport, based on opinions issued by the European Food Safety Authority (EFSA) at the request of the European Commission. Negotiations between the Member States are currently in progress (first half of 2025).

Context as defined by the requesting body

The proposed regulation suggests lower densities (higher space allowances) than those in Regulation 1/2005, in order to improve the space available to the animals being transported and hence their welfare.

Professional organisations in the sector argue that the densities laid down in the current regulation mean that animals transported by road would be less likely to fall due to 'mutual support' between animals. They thus suggest that, if lower densities were applied as recommended in the draft regulation, the animals would be more likely to fall, lose their balance and therefore injure themselves, which would have negative impacts in terms of animal welfare.

Request

For the FRCAW to answer the following question as fully as possible :

> Is it the case that [pigs][1] transported by road at the densities set out in the proposed regulation to revise Regulation No 1/2005 are more likely to fall and/or be injured than [pigs] transported by road at the densities laid down in the current regulation (Regulation No 1/2005)? What factors are likely to affect this risk?

The FRCAW will address only the transport of pigs by road in this report.

Reference documents

- COUNCIL REGULATION (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97
- Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the protection of animals during transport and related operations and amending Council Regulation (EC) No 1255/97 and repealing Council Regulation (EC) No 1/2005

[1] The request as originally worded concerns several species and therefore refers to 'animals', rather than 'pigs'. The present report deals only with the transport of pigs.

+ EFSA AHAW Panel (2022). Welfare of pigs during transport. EFSA Journal 2022;20(8):7421, 317 pp. https://doi.org/10.2903/j.efsa.2022.7421

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Glossary (English version)

Haematoma

Collection of blood outside the blood vessels, in a body space, organ or tissue, as a result of damage to a vessel. The frequency of haematomas in animals may increase as a consequence of losses of balance and falls caused by rough driving (see EFSA, 2022).

Injury

Any damage to the skin, which may take the form of small superficial punctures, scratches, or larger open lesions that are more than skin deep (adapted from Welfare Quality Network, 2019).

Journey duration (EU 'journey time')

In the present report, for the avoidance of ambiguity, 'journey duration' is used in preference to 'journey time' to refer to 'the time period during which animals are moved by means of transport, including the time for loading and unloading the animals' (see the Commission of the European Union 2023 definition of 'journey time').

Loading density

Ratio between the number (or preferably live weight) of animals and the surface area available in the vehicle (usually expressed in kg/m²) (Buckham-Sporer et al., 2023).

Long journey

In the current regulations, a long journey exceeds 8 hours, starting from when the first animal of the consignment is moved (Council of the European Union, 2004).

In the proposed regulation, this is a journey that exceeds 9 hours. A journey starts with the loading of the first animal at the place of departure and ends with the unloading of the last animal at the place of destination (European Commission, 2023).

Road transport vehicle

Means of wheeled transport that is propelled (lorry) or towed (trailer). The characteristics of transport vehicles vary greatly depending on the transporter and the country. They may have 1 to 5 decks, each of which may be divided into 2 to 4 compartments. According to EC regulation 1/2005 (Council of the European Union, 2004) , there are two types of transport vehicle: vehicles used under Type 1 transporter authorisation (< 8 hours) and those used under Type 2 authorisation (≥ 8 hours). In addition to the vehicular features required for both lengths of

journey (weather protection, non-slip flooring surface, appropriate loading and unloading equipment, etc.), Type 2 vehicles must be equipped with a properly insulated light-colour roof, a specified water supply system, an active ventilation system, a temperature control system and a warning system to alert the driver if maximum or minimum temperature limits are reached. For journeys lasting 8 hours or more, animals of all ages must also be provided with appropriate bedding.

Space allowance

Area available per animal (expressed in m^2/animal), generally calculated on the basis of the weight and body dimensions of the animals (Petherick, 2007).

Stress

Stress, including in animals, refers to the presence of negative affective states. These states occur when the animal feels threatened, whether the threat is real or not. In order to adapt to this threat, the animal responds through its behaviour, with reactions of fight or flight if it is afraid, for example, and through its physiology, with an increase in heart rate and the secretion of certain hormones to enable physical effort, among other things.

Transport [2]

The movement of animals effected by one or more means of transport, and the related operations, including loading, unloading, transfer and rest, until the unloading of the animals at the place of destination is completed (Council of the European Union, 2004). *The present report deals only with road transport by lorry.*

[2] In the European Council (2023) proposal, the earlier definition of 'transport' is incorporated into the definition of a 'journey'

Abbreviations

CK or CPK

Creatine kinase (CK) or creatine phosphokinase (CPK)

DFD

Dark, Firm, Dry (term used to describe meat with a dark colour, firm texture and low water content)

EU

European Union

EURCAW

European Reference Centre for Animal Welfare

FRCAW

French Reference Centre for Animal Welfare (English name of the CNR BEA)

IFIP

Institut du Porc (French pig institute)

PSE

Pale, Soft, Exudative (term used to describe meat that is pale, soft and displays significant water loss)

Tables

List of tables

1 Method

Th document provides a synthesis of the information on the risk of falls and injuries associated with loading density set out in the EFSA opinion on the welfare of pigs during transport (EFSA AHAW Panel, 2022). However, in the case of pigs, unlike other species such as cattle and sheep, almost no studies exist that focus exclusively on this issue. The authors of the present report have therefore followed the EFSA opinion in extending the scope of the question to include the impact of multiple factors, including space allowance, on the occurrence of injuries/haematomas, these being frequently studied in the literature, and also the effects of the space allowance on other indicators of pig welfare. The summary of the EFSA opinion provided here has been enhanced by a more comprehensive analysis of the literature on this subject, including grey literature and other articles not cited by the EFSA, with particular attention to studies published since 2022.

The bibliographical corpus was established by first conducting a search on the Web of Science™ (WOS) platform using the following search parameters:

> ("loading densit*" OR "stocking densit*" OR "space allowance*") AND "transport" AND ("welfare" OR "well-being" OR “injur*” OR “wound*” OR “fall*” OR “bruise*”) AND ("pigs" OR "piglet*" OR "swine" OR "boar" OR "sow")

From the 111 documents obtained in the search, 34 titles and summaries of interest were selected, including 9 review articles or chapters in books. These documents contained references to a further 35 documents that were deemed relevant to the subject of this report and were added to the corpus.

The grey literature search was carried out by reviewing all documents relating to animal transport and welfare present on the IFIP, EURCAW-Pigs and European Commission websites. From these sources, 5 documents were selected.

In total, the bibliographical corpus thus comprised 74 documents. Of these, 25 were based on experimental research comparing different loading densities and their contents have been tabulated in the literature review (*Table 2*). The other resources (reviews, surveys, etc.) have contributed to the development of the discussion, recommendations and conclusions in this report.

2 Pig loading densities and space allowances

Loading density refers specifically to the live weight of pigs within a lorry compartment, expressed in kg/m^2, while the space allowance represents the relationship between space and animal in the opposite way, and is often expressed in the literature in m^2/animal (but not in kg). To allow comparison between the various scientific studies discussed here, the unit of measurement mainly used in the present report is surface area in m^2 per 100 kg pig. The EFSA uses the term 'space allowance' to designate the surface area allocated to animals during transport, and this term will therefore be used, where appropriate, in the English-language version of this report.

2.1 Current regulation and practices

Under current European regulations (Council of the European Union, 2004), no requirements are set for loading densities during road transport for specific categories of pig, such as adult breeding animals, fattening pigs weighing more than 100kg, or even piglets. The upper density limit of 235kg/m^2 for pigs of around 100kg that is specified would correspond to pigs being sent for slaughter or young breeding animals travelling to breeding farms.

Pigs weighing over 100kg

For fattening pigs weighing over 100kg, the mortality rate during transport increases with weight (Ellis & Ritter, 2005). This is thought to be related to their stronger metabolic response and increased rectal temperature during transport combined with the lack of specific legislative requirements that recognise their particular needs (Nannoni et al., 2017). In practical terms, the regulatory limit on loading density of 235kg/m^2 allows two pigs of a maximum of 117.5kg live weight to be loaded per m^2. No data is available on the loading densities actually used for heavier animals.

Piglets

The European regulations do not specify space requirements for pigs weighing less than 100kg. The current EU regulatory 235kg/m^2 limit (Council of the European Union, 2004) has recently been criticised by Bracke et al. (2020) as follows: 'this loading density is obviously wrong for the smaller weight ranges. You cannot physically keep 8 pigs of 30kg each on one m^2, without stacking them on top of each other'.

In practice, the space allocated to piglets in transport lorries is measured in terms of the number of piglets per m^2. One survey, conducted in 1999, reported that producer groups loaded an average of 14.6 piglets/m^2 for animals weighing 8kg (i.e., 0.07m^2/piglet or 116.8kg/m^2), and 6.7 piglets/m^2 for animals weighing 20-25kg (i.e., 0.15m^2/piglet or 150.75kg/m^2) (Cauty et al., 1999). A previous survey had reported in 1997 that piglets weighing between 26 and 30kg were generally loaded at densities of around 162kg/m^2, i.e. approximately 0.17m^2/piglet (Riches & Guise, 1997).

2.2 Proposal for a new regulation

Chapter VII (Clause 2) of the recent proposal for an EU regulation on the transport of live animals (European Commission, 2023) (available online here) now proposes that the space allowance for transport by road, rail and sea should be based on the following allometric equation: $A = k*W^{(2/3)}$, where A = area per animal (in m^2), W = live weight of the animal (in kg), and k is the constant (k-value) specific to a given animal species or category. The k-value for pigs is **0.027**.

It is proposed that the minimum space allowance in area per pig during transport must comply with the figures set out in EFSA (2022), as summarised in *Table 1.*.

2.3 The EFSA's view

To assess the minimum space requirements for pigs during transport, the EFSA's approach is as follows:

> During transport, pigs require a minimum space that will accommodate (a) their **physical size in a standing (or sternally lying) posture** [sternally lying = legs tucked close to and under the body], and thereby allow them to (b) **adjust their posture** in response to acceleration and other events, (c) [simultaneously] **rest in a normal semi-recumbent lying posture**, (d) **thermoregulate** [by lying in *full lateral recumbency*] and (e) [move around to] **eat and drink**, if feed and water are provided in the means of transport. Recommendations for a minimum space allowance will be set by the first limiting factor that reduces the ability of the pigs to undertake one of the above biological requirements, i.e. whichever of the above requirements needs the most space. (based on EFSA, 2022, 3.5.3.2)[3]

[3] Explanatory text in square brackets is taken from elsewhere in EFSA (2022). Bold and italic fonts are added by the FRCAW.

The EFSA states that the scientific evidence available is insufficient to quantify the minimum space required to fulfil biological functions (b), (d) and (e) under transport conditions. Using the allometric equation $A = k*W^{(2/3)}$ (where A is area in m^2 per animal and W is live weight in kg), the available data on the space required to fulfil biological functions (a) and (c) leads the EFSA to suggest that a k-value of at least 0.027 is required for all categories of pigs.

Table 1. shows calculations of minimum space allocations for pigs during transport using the allometric equation $A = 0.027 \times W^{(2/3)}$ suggested by the EFSA. Use of this k-value would, the EFSA says, give estimates allowing all the pigs occupying a vehicle compartment to lie simultaneously in a semi-recumbent position.

***Table 1.* Estimates of the suggested minimum space allowance for different weights of pigs during transport that would permit all pigs to simultaneously lie in a 'semi-recumbent' position (using k-value = 0.027, suggested in EFSA, 2022)**
Values for pigs weighing 100kg (reference) are shown in red.

Pig weight (kg)	10	30	40	100	120	140	160	180	200	220	240	260	280	300
Space allowance (m^2/pig)	0.13	0.26	0.32	0.58	0.67	0.74	0.79	0.88	0.94	1.00	1.04	1.12	1.18	1.23
Density (kg/m^2)	79.2	113.8	125.1	169.3	179.8	189.2	197.7	205.5	212.8	219.6	226.0	232.0	237.8	243.3

2.4 Particular needs of piglets

If the current regulatory EU loading density limit of $235kg/m^2$ were applied when loading piglets for transport, this would entail minimum space allowances of $0.09m^2$/ 20-25kg piglet and $0.13m^2$/ 30kg piglet. In practice, though, the literature suggests that producers allocate a greater surface area per piglet than required by the regulation (*Table 1*), although it should be noted that the available data are derived from studies carried out in the 1990s (Riche & Guise, 1997; Cauty et al., 1999) and that more up-to-date figures are not provided in the literature. Under the recommendations in the regulatory proposal, which are derived from the allometric equation proposed by Petherick & Phillips (2009) on which the EFSA opinion was based, the space allowance would be $0.22m^2$ for piglets weighing 20-25kg and $0.26m^2$/piglet weighing 30kg. These values are higher than those currently used on the ground (*Table 1*).

Table 1. **Space allowances for piglets during transport according to current EU regulations, in practice, and as detailed in the new regulatory proposal**

Piglet weight	Minimum space allowance based on a regulatory density of 235kg/m² (m^2/piglet) *	Surface area allocated in practice (m^2/piglet) **	Minimum space allowance in the regulatory proposal (m^2/piglet)
20-25kg	0.09	0.15	0.22
30kg	0.13	0.17	0.26

* example of calculation for piglets weighing 30kg: 30/235 = 0.13m^2/piglet

** surveys conducted in the 1990s

3 Bibliographical analysis

3.1 Calculating space allowances for pigs

For 'short' journeys, i.e. less than 8 hours (Council of the European Union, 2004), Petherick & Phillips (2009) proposed a space allowance per animal (all livestock) based on the allometric equation: $A=k*W^{2/3}$, with a k-value of 0.020. For longer journeys, on which it is desirable for all the animals to be able to lie down and rest simultaneously, the authors considered that a k-value of 0.027 would be sufficient (Petherick & Phillips, 2009). On this basis, the space allowance for 100kg pigs on short journeys would be 0.43m^2/pig (232kg/m^2), which is close to the highest permitted loading density in the current regulations (235kg/m^2), and that for pigs of the same weight on longer journeys would be 0.58m^2/pig (169.3kg/m^2), which matches the space allowance in the December 2023 regulatory proposal, derived from the EFSA opinion (EFSA AHAW Panel, 2022).

Whiting (2024) has claimed that a pig's ability to lie down during transport should be a minimum legal requirement. The area occupied by a 100kg pig lying down has been calculated to be 0.39m^2 (256kg/m^2) for a sternal position (legs tucked under the body), while full recumbency, with the pig stretched out, would require 1.05m^2 (95kg/m^2) (Baxter, 1992). Baxter's (1992) figure for the sternal position is in line with the current regulations and with the conclusion drawn by Lambooy & Engel (1991), based on observations inside a transport vehicle of 100kg pigs, that a space allowance of 0.43m^2/100kg (232 kg/m^2) will allow all pigs to lie down at the same time, but not fully stretched out. However, when ambient temperatures are high (see *Section 3.3.3*), the current European regulations, which are based on data from older studies, do not specify a sufficient space allowance for pigs of

modern genetic origin, these animals being longer and heavier than the pigs of the 1980s. These pigs need enough space to be able to move around in transport vehicles in order to access water points(Duval et al, 2024), and to lie in full recumbency so that they thermoregulate effectively (Arndt et al., 2019). A FRCAW report was published on the impact of extreme temperatures during the transport of pigs in 2025 (CNR BEA, 2025).

Sows weighing around 235kg occupy between 0.42 and 0.47m^2 when standing, and up to 0.53-0.63m^2 when lying down (Arndt et al., 2020). In line with the allometric equation in Petherick & Phillips (2009), the new regulation proposes an allowance of 1.04m^2 for animals of this weight (EFSA AHAW Panel, 2022), this being the area specified by the EFSA that would allow all sows to simultaneously lie semi-recumbent.

Piglets

The few available results suggest that high loading densities do not affect piglet welfare during transport (Riches & Guise, 1997). Indeed, huddling and lying in complete contact with the body of a congener is a common thermoregulatory behaviour observed in young piglets during transport, diminishing with age (Camerlink et al., 2022). Whether piglets choose to lie in bodily contact with their conspecifics is also dependent on the ambient temperature (Spoolder et al., 2012). The study by Riches & Guise (1997) was conducted at low temperatures (0-10°C). From the available literature, it is not known whether piglets would voluntarily huddle in a transport vehicle at higher ambient temperatures.

3.2 Comparative studies of different space allowances during transport

3.2.1 Summary table

The impact of loading densities on the risk of pigs falling and injuring themselves in a transport vehicle has not been specifically studied in the literature. The corpus does, however, contain a certain amount of information on the impacts of loading densities on various welfare indicators, including injuries, although the causes of such injuries are not always clearly identified. *Table 2* summarises the results of 21 experimental studies that compared different space allowances, together providing information on the following indicators in finishing pigs: behaviours (resting postures, activity, aggression, panting); animal physiology (hormonal and biochemical parameters, immune system); mortality during transport; and post-mortem characteristics of the meat (lesions/haematomas observed on the pig on arrival, or on the carcass). Such indicators are often complementary and were measured in parallel to offer the best interpretation of the results in terms of animal welfare.

One study (Bryer et al., 2011) in *Table 2* reported results for 90kg gilts. Four further experimental studies discussed weaners. These have been analysed separately and are not included in the table.

The in-vehicle space allowances described have been converted to m^2/100kg pig to facilitate comparison between the different studies.

Of the 21 studies listed in *Table 2*, 16 compared different in-vehicle space allowances (some regulatory, others not) and concluded that the highest allowances produced global improvements to pig welfare and/or meat quality according to the different parameters observed. These are marked with a '+' in the Conclusion column of the table. Of the 16 studies whose conclusions supported an increase in space allowance, 4 included a surface area per animal close to the allowance in the new regulatory proposal (≥ 0.56 m^2/100kg) in their design.

The first 8 studies listed in *Table 2* compared at least two space allowances that met the current (EU) regulatory threshold, sometimes also including allowances falling below the regulatory threshold in the comparison.

Of the 21 studies in the table, 5 concluded that both excessively high and excessively low loading densities would reduce animal welfare and/or meat quality. These studies are marked with a '-' in the Conclusion column of the table. Their authors recommended a space allowance that fell between the two 'outer' densities in their studies. In all five, the lower density (higher space allowance) complied with current regulations.

The analysis conducted by the FRCAW of the articles listed in *Table 2* focuses on two main areas, examining in turn the influence of the space allowance during transport on **1) the risks of falls and injuries** and **2) other welfare indicators** for finishing pigs (behaviours, animal physiology, mortality and meat quality).

The behavioural and physiological results in these studies could usefully be divided into two groups, based on the relationship between the space allowances compared and the current and proposed regulations:

- Studies that compared space allowances meeting the current (EU) regulations ([0.42 - 0.58]m^2/100kg) with a space allowance that met the new regulatory proposal (> 0.58m^2/100kg)
- Studies that compared space allowances meeting the current (EU) regulatory threshold but falling below the new proposed regulation ([0.42 - 0.58]m^2/100kg).

The few studies that addressed the specific case of piglets at different loading densities reported only behavioural and physiological results. These studies are therefore discussed separately, following the discussions of comparative studies in *paragraphs 3.2.3.1 and 3.2.3.2* .

Table 2. Summary of the results of experimental studies on the impact of the space allowance during the transport of pigs (live weigh = 72 - 135kg, depending on the study) on various welfare indicators.

Figures in green boxes correspond to the new regulatory proposal (≥ 0.58m²/100kg), those in blue boxes correspond to the range between the current regulatory threshold and the new proposal ([0.42 - 0.58]m²/100kg), and those in red boxes are below the current regulatory requirements (< 0.42m²/100kg). Studies are ranked in descending order from the highest allowance to the lowest. The first eight studies listed compared different allowances meeting the current regulatory threshold (EU) and are shown on the first page of the table.

NS: non-significant differences between the allowances compared. '/' indicates that the parameters were not measured. Abbreviations for physiological parameters: CK: creatinine kinase, CPK: crea tinine phosphokinase, LDH: lactate dehydrogenase, G:L: granulocyte/lymphocyte ratio, ACTH: adrenocorticotrophic hormone, RBC: red blood cells, HGB: haemoglobin. Meat quality parameter abbreviations: L: luminosity, a*: red/green, b*: yellow/blue, fpH: final carcass pH (= conversion of residual glycogen to lactic acid completed), FOP: Fibre optic probe, PSE: pale, soft, exudative, DFD: dark, firm, dry, RFN: red, firm, non-exudative.*

Reference (references cited in the EFSA opinion are **in bold**)	**Average weight of pigs (kg)**	**Total number of pigs transported**	**Journey duration (h)**	**Number of repetitions of a trip (total trips)**	**Space allowances compared in the study (m²/100kg pig)** green: allowances meeting proposed regulatory requirement (≥ 0.58m²/100kg) blue: allowances meeting current EU requirement (≥ 0.42m²/100kg) red: allowances below current EU requirement (< 0.42m²/100kg)						**Behavioural responses**	**Physiological stress responses**	**Injuries/mortality**	**Meat quality outcomes**	**Conclusion**
Lambooy et al. (1985) https://doi.org/10.1016/0301-6226(85)90007-7	103	216	44h	6 (1)	0.64	0.43			0.32		Lowest space allowance (0.32m²/100kg pig): difficulty lying down simultaneously and more frequent posture changes (descriptive, no figures) Highest space allowance (0.64m²/100kg pig): pigs lay down more and sooner after departure (descriptive, no figures)	Lowest space allowance: ↓ % hematocrit glucose: NS	/	Lowest space allowance: ↑ carcass pH_{45min} ↑ carcass pH_{18h} ↑ muscle temperature Medium space allowance (0.43m²/100kg): ↑ muscle temperature (vs highest allowance) ↓ carcass weight (vs highest allowance)	+
Pasquale et al. (2024a) https://doi.org/10.1139/cjas-2024-0038	~ 100kg?	1386	1h50	3 (6)	0.59	0.49	0.46				Postures, drinking : NS Lowest space allowance: ↑ lying behaviours on arrival (trend)	NS	/	Medium space allowance: ↑ L* (upper deck)	+
Guise & Penny (1989) https://doi.org/10.1017/S0003356100032724	71.8	1351	~ 2h30	8 (8)	> 0.56	0.42					/	/	Lowest space allowance: ↑ marks on skin ↑ rectal prolapse	Lowest space allowance: ↓ FOP (= DFD meat)	+
Guerritzen et al. (2013) https://doi.org/10.1017/S1751731113001523	110	368?	8h	4 (4)	0.56	0.44					Lowest space allowance: ↓ resting behaviours (lying down) Aggressive behaviours: longer fights Drinking: NS	Lowest space allowance: ↑ body temperature ↑ heart rate (trend) ↑ [ ]* CK (trend) Other parameters (hematocrit, cortisol, glucose, etc.): NS	/	/	+
Lambooy & Engel (1991) https://doi.org/10.1016/0301-6226(91)90006-C	110	660	25h	2 (11)	0.54	0.43		0.35			Highest space allowance: pigs lay down more and sooner after departure (descriptive, no figures)	/	/	Lowest space allowance: ↑ pH_{45min}	+
Urrea et al. (2021) https://doi.org/10.1093/jas/skab119	118.9	1936	8h30	6 (8)	0.50	0.43		0.37			Lowest space allowance: During transport: ↓ time spent lying ↑ time spent sitting (vs highest allowance) On arrival (after 8h journey): ↑ time spent lying ↓ time spent drinking immediately on arrival (highest space allowance = medium allowance > lowest allowance) Aggressive behaviours: NS	Lowest space allowance: ↑ [ ]* CK (vs highest allowance)	Lowest allowance: ↑ lesion score (trend)	Lowest space allowance: ↓ pH_{1h} (vs higest allowance) (trend))	+
Barton Gade & Christensen (1998) https://doi.org/10.1016/S0309-1740(97)00098-3	101	774	1h30-2h	2 (8)	0.50	0.42	0.39	0.35			Higher space allowances: pigs do not lie down more, but display more activity and associated losses of balance (descriptive, no figures)	Highest space allowance: ↓ [ ]* CK Other parameters (lactate, cortisol, etc.): NS	Highest and lowest space allowances: ↑ marks on carcass score Lesion score (feet, body, shoulders) influenced by space allowance Highest space allowance: ↓ scores overall (vs 0.42 m²/pig) (no post-hoc tests)	Highest and lowest space allowances: pH, meat DFD/PSE etc.: NS	
An et al. (2023) https://doi.org/10.5187/jast.2023.e34	~ 100kg?	3903	~ 0.5h	6 (10)	> 0.43	0.37-0.43		< 0.37			Highest space allowance: ↓ time spent lying ↑ time spent sitting ↑ overlapping Highest and lowest allowances: ↑ aggressive behaviours	Highest and lowest space allowances ↑ breathing rate	/	Highest space allowance: ↑ carcass weight ↑ backfat thickness ↑ carcass quality score Medium space allowance: ↑ % RFN	-

Reference (references cited in the EFSA opinion are **in bold**)	**Average weight of pigs (kg)**	**Total number of pigs transported**	**Journey duration (h)**	**Number of repetitions of a trip (total trips)**	**Space allowances compared in the study (m^2/100 kg pig)** green: allowances meeting proposed regulatory requirement (≥ 0.58m^2/100kg) blue: allowances meeting current EU requirement (≥ 0.42m^2/100kg) red: allowances below current EU requirement (< 0.42m^2/100kg)						**Behavioural responses**	**Physiological stress responses**	**Injuries/mortality**	**Meat quality outcomes**	**Conclusion**
Hunter et al. (1994)	100	1500	?	4 (12)	0.50		0.38	0.33			Postures: NS	/	/	Lowest space allowance: ↑ DFD meat (summer) ↑ fpH (summer) Highest space allowance: ↑ score for marks on carcass (summer)	+
Guise et al. (1998) https://doi.org/10.1016/S0309-1740(98)00056-4	95	2496	3h	2 (16)	0.49	0.41		0.36	0.32		/	/	/	Lowest space allowance: ↓ carcass weight (vs lowest space allowance) Other parameters (pH, quality score, muscle colour, etc.): NS	+
Warriss et al. (1998) **https://doi.org/10.1016/S0309-1740(98)00057-6**	95	2496	3h	2 (16)	0.49	0.41		0.36	0.32		/	Lowest space allowance: ↑ [ ]* CPK Other parameters (cortisol, glucose, lactate, [ ]* proteins, osmolality, etc.): NS	/	Meat quality (fpH, L*, water loss etc.): NS	+
Cobanovic et al. (2023) https://doi.org/10.2478/aoas-2022-0093	109.5	1080	2 lengths: < 1h and > 3h	2 (10)	> 0.46		0.36-0.41		< 0.32		/	/	Highest and lowest space allowances: ↑ severe lesions Lowest space allowance: ↑ lesions on front and middle parts of carcass Highest space allowance: ↑ lesions on rear part of carcass	/	-
Pereira et al. (2015) https://doi.org/10.5424/sjar/2015133-6638	115.5	192	~ 5h	8 (1)	0.45		0.39	0.35			/	Highest space allowance: ↑ LDH ↑ cortisol (vs medium allowance) Highest and lowest space allowances: ↑ % hematocrit Other parameters (immune system, etc.): NS	Highest space allowance: ↑ 1-5 cm lesions Lowest space allowance: ↑ 5-10 cm and 10-15 cm lesions	Highest space allowance: ↑ L*, a*, b* (0.45 m^2/pig = 0.39 m^2/pig > 0.35 m^2/pig) ↑ pH_{45min} and fpH Medium space allowance: ↓ water loss ↑ pH_{45min} (vs lowest allowance) ↓ fpH (vs lowest allowance)	-
Bryer et al. (2011) https://doi.org/10.1016/j.livsci.2010.09.026	gilts: 90kg	80	5 lengths: [6h – 30h]	5 (2)	0.45		0.37				/	Lowest space allowance: ↑ G:L ratio after 18 hours ↑ % hematocrit after 6 hours ↑ hemoglobins after 6 and 18 hours [ ]* CK: 0.37 m^2/pig > untransported control 0.45 m^2/pig = untransported control Other parameters (cortisol, glucose etc.): NS	/	Lowest space allowance: reduction in body weight greater after 18h (trend)	+

Reference (references cited in the EFSA opinion are **in bold**)	**Average weight of pigs (kg)**	**Total number of pigs transported**	**Journey duration (h)**	**Number of repetitions of a trip (total trips)**	**Space allowances compared in the study (m^2/100kg pig)** green: allowances meeting proposed regulatory requirement (≥ 0.58m^2/100kg) blue: allowances meeting current EU requirement (≥ 0.42m^2/100kg) red: allowances below current EU requirement (< 0.42m^2/100kg)						**Behavioural responses**	**Physiological stress responses**	**Injuries/mortality**	**Meat quality outcomes**	**Conclusion**
Chai et al. (2010) https://doi.org/10.1016/j.livsci.2009.09.014	92.5	432	3 lengths: [40 min – 5h)	8 (1)	0.43		0.37			0.30	/	Lowest space allowance: ↑ LDH ↑ cortisol (trend) ↑ ACTH ↑ [ ]* CK Highest space allowance: ↓ Lactate Other parameters (glucose, hematocrit, RBC, HGB, immune system etc.): NS	/	Highest space allowance: ↓ pH ↓ muscle colour Water loss: NS	+
Čobanović et al. (2016) https://doi.org/10.1515/acve-2016-0015	120	480	1-2h	4 (16)	> 0.50			[0.30-0.50]		< 0.30	/	/	Lowest space allowance: ↓ lesion score (vs highest allowance)	Lowest space allowance: ↑ PSE meat (when lesion score is high) Highest space allowance with high lesion score: ↑ pH_{45min} ↑ carcass temperature ↑ DFD meat	-
Pilcher et al. (2011) https://doi.org/10.2527/jas.2010-3143	124.7	17652	2 lengths: < 1h and 3h	2 (80)	0.42	0.39	0.37	0.35	0.34	0.32	3 lowest space allowances (0.32, 0.34 and 0.35 m^2/pig): ↑ panting (short journeys) 2 lowest space allowances (0.32 and 0.34 m^2/pig): ↑ skin discolouration	/	% mortality and non-ambulatory pigs: NS	/	+
Pasquale et al. (2024b) https://doi.org/10.1139/cjas-2024-0039	135.5	1488	1h49	3 (6)		0.39		0.34			Postures, drinking: NS	Lowest space allowance: ↓ hematocrit levels (trend) ↑ [ ]* CK (trend)	Lowest space allowance: ↑ lesion score (second deck)	/	+
Ritter et al. (2007) https://doi.org/10.2527/jas.2007-0232	131.2	4662	3h	1 (42)	0.40	0.37	0.35	0.33	0.32	0.30	/	/	% mortality increases when space allowances decrease	/	+
Ritter et al. (2006) https://doi.org/10.2527/jas.2005-577	129	12511	3h	8 (74)			0.37			0.30	/	/	Lowest space allowance: ↑ % total losses (deaths and non-ambulatory) ↑ % non-ambulatory uninjured pigs ↑ % mortality (trend) % non-ambulatory injured pigs: NS	/	+
Kim et al. (2004) https://doi.org/10.5713/ajas.2004.116	110	114	2 lengths: 1h and 3h	1 (2)		0.39		0.35		0.31	Highest space allowance: ↓ standing postures ↑ sitting postures	Highest space allowance: ↓ glucose (vs medium allowance) ↓ [ ]* CK (trend) ↓ LDH	/	Lowest space allowance: ↑ PSE meat Other parameters (pH, muscle colour): NS	+

3.2.2 Impacts of space allowances on the risks of falls and injuries

Risk of falls

Broom (1993) asserts that the idea that animals are protected against falling by being packed closely together is erroneous unless a vehicle is driven badly. He suggests that quadrupeds prefer to stand with their legs slightly spread out, 'so that they will not stumble or fall when the vehicle moves. Hence they do not touch one another if they are able to avoid doing so.' (Broom, 1993). (It should be noted that no experimental studies have been encountered by the authors of the present report on which these observations are based).

No scientific study has looked specifically at the risk of falls in relation to loading density during the transport of pigs, nor has this parameter been measured in such a way as to enable comparison of the proposed new regulatory space allowances (European Commission, 2023) with those of the current regulation (Council of the European Union, 2004). One often-cited study on this issue is that of Barton Gade & Christensen (1998), who suggested that the transport of pigs in a more restricted space (0.35 and 0.39m^2/100kg pig) allowed animals to support each other against vehicle movements. In their study, animals provided with higher space allowances (0.43 and 0.50m^2/100kg) were observed to change position and move around the vehicle more, and to have more difficulty keeping their balance when the vehicle negotiated bends and poor surfaces. This suggests that they might be at increased risk of falls and injuries from such driving events (and also from harsh acceleration and braking). However, the authors also indicated that a higher space allowance would allow animals to sit or lie down to avoid having to keep their balance. The reported difficulties with balance were not quantified in this study, and this lack of statistical evidence makes it impossible to ascertain precisely whether a higher space allowance during transport would increase the risk of falls. Barton Gade & Christensen (1998) also emphasised that a rougher ride is a further risk factor (see *Section 3.3.1*).

Risk of injuries

While no research studies contain quantitative data based on direct observations of animals' loss of balance as a function of the space available to them in a transport vehicle, a number of studies have instead used the presence of lesions and haematomas, observed on the animals' arrival at the abattoir or on their carcasses after slaughter, as indirect indicators of the falls and impacts experienced during transport. These studies are listed here, although it should be pointed out, that this measure lacks precision, since lesions and haematomas may have been caused by other circumstances and events during transport (aggression, mounting/overlapping). They may also have occurred during other phases of the production chain, either while the animal was still living on farm, or as the result of falls on the access ramp or inappropriate handling by operators during loading or unloading.

Whatever the cause, the probability of an animal incurring injuries was often found to be greater where loading densities were high. Indeed, most studies reported that lack of space

in the transport vehicles made it impossible for pigs to lie down simultaneously, meaning that they were unable to rest. The animals physically competed for the space, resulting in constant changes of position, fighting and trampling, which caused skin damage (Faucitano, 2001) from bites and scratches. Further, the animals' fatigue from lack of rest increased the risk of falls during unloading and made the pigs more difficult to handle (Sardi et al., 2020; Zappaterra et al., 2023), while the use of electric prods during unloading could also cause haematomas (Urrea et al., 2021). Consequently, the total incidence of skin lesions and bruises observed on pig carcasses following transport, from all causes (whether incurred directly during transport itself or from peripheral activities such as handling during unloading), increased as the space allowance during transport decreased (Čobanović et al., 2023; Urrea et al., 2021; Pasquale et al., 2024b) (*Table 2*). Even when the space allowance was in line with the current regulations (0.42m^2/100kg), more haematomas were observed on the animals compared to pigs with a larger space allowance (0.56m^2/100kg) (Guise & Penny, 1989). Additionally, the space allowance had a significant influence on the skin lesion severity scores observed on the pigs, with a greater number of severe lesions at 0.42m^2/100kg than at 0.50m^2/100kg (Barton Gade & Christensen, 1998) (*Table 2*). It should be noted, however, that in the study by Urrea et al (2021), lesion scores did not differ between space allowances of 0.43 and 0.50m^2/100kg.

By taking the anatomical location of injuries on the body into account when observing carcasses on the slaughterline following transport, Čobanović et al. (2023) sought to relate the prevalence of lesions to pre-slaughter factors. Their study included the relationship between loss of balance in the form of falls, trampling and impacts in the vehicle and different loading densities. Aggressive behaviours have been found to result in bite injuries to the front of the body (head, shoulders and back) (Driessen et al., 2020), while mounting leads to injuries on the hind quarters and mid-back (Faucitano, 2001; Driessen et al., 2020). Injuries from human intervention (use of electric prods) are mainly found on the hind quarters (Čobanović et al., 2023). On this basis, Čobanović and colleagues showed that a space allowance of > 0.50m^2/100kg pig, higher than the regulatory threshold of > 0.46m^2/100kg, caused pigs to develop severe lesions on the front and hindquarters of the carcass that were more numerous than at an intermediate space allowance close to the regulatory threshold (0.40-0.45m^2/100kg) (Čobanović et al., 2023). The authors attributed these injuries to falls occurring during transport where animals were spaced too widely to be able to cope with poor road surfaces and/or rough driving (sudden acceleration and violent braking). At the lowest space allowance (< 0.35m^2/100kg), the results showed more lesions than at the two higher allowances. In this instance, injuries were on the front and mid parts, and were attributed to fighting between pigs (Čobanović et al., 2023). The results of this study were in agreement with the conclusion of Čobanović et al. (2016), which had concluded that high lesion scores were related to the fact that the space allowance was either too small (< 0.30m^2/100kg) or too large (> 0.50m^2/100kg). The authors therefore recommended an intermediate space allowance. In another study, the highest space allowance (0.45m^2/100kg) was associated with a greater number of small skin lesions (1-5 cm) while a lower allowance (0.35m^2/100kg) was accompanied by a greater number of

severe lesions (5-15 cm) (Pereira et al., 2015) (*Table 2*). The authors suggested that the increase in the number of small lesions with a higher space allowance could result from brief overlaps between conspecifics followed by rapid separations during loss of balance, generating light scratches on the back. On the other hand, a smaller space allowance would restrict the opportunity for the animals to separate, resulting in prolonged leaning on the backs of fellow animals and longer, deeper scratches.

In conclusion: Although the risk of falls was sometimes discussed in the literature, no piece of research has specifically taken the risk of falls in relation to density during the transport of pigs as its main object of study. This impact has been assessed indirectly through injuries observed on the carcasses. The injuries attributed to falls (falls themselves were not directly observed in the studies) might occur where animals were too widely spaced on journeys that also involve poor road surfaces and/or rough driving. However, at higher space allowances, there was generally a decrease in the incidence of lesions and bruises observed on the carcasses of pigs after transport, whatever the cause (falls, aggression, overlapping, fatigue, human intervention) and at whatever point they occurred (during transport itself, while loading and unloading, in lairage or holding pens). Some authors attributed this result to a reduced need for interventions during unloading, as the pigs were less tired. In addition, a larger space allowance in the lorry allowed animals to sit or lie down, reducing the risk of falls. On the evidence in the literature, space allowances similar to the new regulatory proposal would not appear to cause more injuries than allowances that strictly comply with the current regulatory threshold for minimum welfare. In particular, one study has recorded fewer haematomas at a space allowance of 0.56m^2/100kg than at 0.42m^2/100kg.

3.2.3 Impacts of space allowance on other welfare indicators

3.2.3.1 Impacts of space allowance on pig behaviours

The data are conflicting on whether pigs prefer to stand or lie down during transport, and this behaviour would appear to depend on the length of the journey (see *Section 3.3.2*) and its timing (season, time of day). While in the lorry, pig behaviour changes over time. During loading and immediately after departure, the pigs mostly stand upright and are active. The pigs explore their new environment and look for a place to sit or lie down (Lambooy & Engel, 1991). It is mainly during this phase - when animals unknown to each other are trying to establish a hierarchy - that a high level of activity sometimes occurs, linked to aggressive behaviour (Bradshaw et al., 1996 b; Gerritzen et al., 2013). Connell (1984) suggests that pigs do not fight while the vehicle is moving but will do if it is stationary. However, Lambooy & Engel, (1991) observed no fighting when the vehicle was halted during a long journey. After 30 minutes, pigs begin to lie down (Barton Gade & Christensen, 1998) on journeys of up to 2 hours (Lambooy et al., 1985; Gerritzen et al., 2013). If the space allocation is reduced, animals lie down more frequently when the vehicle is stationary during the driver's breaks (Lambooy & Engel, 1991).

3.2.3.1.1 Comparisons of space allowances in line with current (EU) regulations ([0.42 - 0.58]m^2/100kg) with space allowances over the proposed new regulatory threshold (> 0.58m^2/100kg)

One study suggested that a space allocation of 0.64m^2/100kg would allow pigs to rest better (Lambooy et al., 1985). Although their observations were descriptive only, the authors noted that pigs at this allowance lay down sooner after departure than at 0.43m^2/100kg, and that the majority of pigs lay down at the largest space allowance. A more recent study compared two space allowances within current regulations (0.46 and 0.49m^2/100kg pig) with an allowance higher than that in the new regulatory proposal (0.59m^2/pig) (Pasquale et al., 2024a). The authors observed no significant difference between the postures adopted by the three groups while in the lorry (*Table 2*). However, the group at the lowest space allowance in the lorry (0.46m^2/100kg) displayed more resting behaviours on arrival at the abattoir, suggesting greater fatigue. Indeed, pigs that are fatigued on arrival at an abattoir have been observed to prefer to lie down to recover from the stress of transport rather than devote their time to other activities (Brandt & Aaslyng, 2015).

3.2.3.1.2 Comparisons between space allowances above the current (EU) regulatory threshold (> 0.42m^2/100kg) but below the new regulatory proposal (0.58m^2/100kg)

In their study, Gerritzen et al (2013) observed the behaviour of pigs transported for 7 hours, comparing a space allowance during transport slightly above the regulatory allowance (0.44m^2/100kg pig) with a higher allowance (0.56m^2/100kg pig), close to the threshold of 0.58m^2/100kg pig in the new regulatory proposal. Aggressive behaviours occurred during loading and immediately after departure, but also towards the end of the journey. Fights lasted longer in pigs transported at 0.44m^2/100kg compared with pigs transported at 0.56m^2/100kg (*Table 2*). Drinking behaviour did not differ between the two groups (1L consumed/pig during the 7-hour journey). Approximately 2 hours after departure (initial departure and following a break), pigs at 0.56m^2/100kg pig spent more time lying down. Conversely, pigs at 0.44m^2/100kg lay down more when the lorry was stationary (during driver breaks and on arrival at destination), suggesting greater fatigue (Gerritzen et al., 2013). These results are in line with previous studies by Lambooy and colleagues observing long journeys (25 to 44 h). Those studies suggested that pigs transported at allowances greater than or equal to 0.54m^2/100kg were better able to rest – they lay down sooner after departure and the number of pigs lying down was higher than at 0.43m^2/100kg (Lambooy et al., 1985; Lambooy & Engel, 1991).

According to Pasquale et al. (2024a), pigs transported at allowances of 0.49 and 0.46m^2/100kg adopted similar postures while in the lorry (*Table 2*). Comparing an allowance greater than 0.43m^2/100kg with an experimental allowance of between 0.37 and 0.43m^2/100kg, An et al. (2023) also observed no differences between the postures adopted by pigs in the lorry. They observed more fighting at the higher allowance, whereas other authors have noted no effects on aggressive behaviours when comparing space allowances of 0.50, 0.43 and 0.37m^2/100kg (Urrea et al., 2021). In this last study, on arrival at the

destination, the selected indicators of fatigue (lying down, less drinking behaviour, aggression) did not differ between pigs at an allowance of 0.43m^2/pig and those at a higher allowance (0.50m^2/pig) (Urrea et al., 2021). The study would apepar to indicate that an increase of 0.07m^2/100kg pig compared with the regulatory minimum would have little impact on the fatigue of pigs once they reach the abattoir.

The case of piglets

During a 24-hour transport period, early-weaned piglets weighing approximately 6.5 kg were observed to spend 75.6% of the time lying down and 21.6% of the time standing (Lewis & Berry 2006). Indeed, elsewhere, the effects of the space allowance on piglet welfare during transport were mainly manifested in terms of positional changes, with 5kg weaned piglets transported at 0.05m^2/piglet standing or sitting more frequently and lying less often than piglets with more space (0.06 and 0.07m^2/piglet) (Sutherland, Bryer et al., 2009; Sutherland, Krebs et al., 2009). A further study by Sutherland and her team reported an increase in lying and a reduction in 'standing-rearing on another pig' in weaned piglets transported with an allowance of 0.06m^2/piglet, suggesting that this space allowance would be more suitable for transport than the other two tested (0.05 and 0.07m^2/piglet) (Sutherland, Bryer et al., 2010). In older piglets weighing 30kg, Riches & Guise (1997) reported that 45% lay or sat, and 55% stood, regardless of the space allowance (0.14, 0.17 or 0.22m^2/piglet). Further, all piglets lay down when the vehicle was stationary. When the lorry was not moving, the piglets lay on top of each other, thereby voluntarily increasing the density by 30kg/m^2 at the highest space allowance. The authors suggested that the highest allowance in the study, which exceeded the regulatory threshold (*Table 1*), enabled piglets to express a choice (either lying on top of each other and thereby effectively increasing density, or lying in contact with the ground), which would reduce the stress of transport.

In conclusion: Pigs provided with a space allowance close to or greater than the threshold in the regulatory proposal (0.58m^2/100kg) are better able to rest (they lie down more) during transport, and are less fatigued on arrival at the abattoir than pigs at a lower space allowance. Further, when fights between fellow pigs do occur, they are shorter. The comparison of space allowances from 0.42 to 0.58m^2/100kg has revealed few differences in pig behaviours (posture, aggressive interactions). The behaviour of 30kg piglets would appear to be similar whether they are transported at allowances of 0.14m^2/piglet (current EU regulations, cf. Table 2), 0.17m^2/piglet (actual practice in the sector) or 0.22m^2/piglet (below the allowance 0.26m^2/piglet in the new regulatory proposal).

3.2.3.2 Impacts of space allowance on physiological indicators

As previously noted, the limited space available in a transport vehicle obliges pigs to increase their physical activity to negotiate the shared space. This often causes fatigue in pigs (Benjamin, 2005). Body temperature, respiratory rate and heart rate are sometimes used as indicators of excessive activity or stress in the literature dealing with different loading

densities during transport (An et al., 2023; Gerritzen et al., 2013). The presence of muscle fatigue after transport is mainly measured by creatine kinase (CK) levels, an enzyme released in the metabolic process of energy recovery (Warriss et al., 1998; Knowles & Warriss, 2007), and by increases in lactate and the enzyme lactate dehydrogenase (LDH) (Li et al., 2008). Plasma glucose levels also rise during excessive exertion or transport stress (Bryer et al., 2011; Terlouw & Bourguet, 2022), while indicators of dehydration (increased haematocrit and haemoglobins) can reflect excessive physical activity combined with a lack of water intake (Mota-Rojas et al., 2012). When pigs are exposed to stressors such as road transport, the response of the hypothalamic-pituitary-adrenal (HPA) axis is accompanied by the release into the blood plasma of stress hormones, mainly cortisol and corticotropin (ACTH) (Bradshaw et al., 1996a; Li et al., 2008). The immune system response in pigs during transport is mainly indicated by a decrease in lymphocyte numbers (Pereira et al., 2015) or increases in granulocyte/lymphocyte (G:L) and neutrophil/lymphocyte (N:L) ratios that are directly triggered by the presence of stress hormones (Sutherland et al., 2009b; Bryer et al., 2011). Many studies have used these various physiological parameters to assess the impacts of different space allowances on increased physical activity, muscle fatigue and stress in pigs. The following discussion concerns those studies that have compared space allowances meeting the current regulations either with each other or with allowances over the threshold in the new regulatory proposal (*Table 2*).

3.2.3.2.1 Comparisons of space allowances in line with current (EU) regulations [0.42 - 0.58]m^2/100kg with space allowances over the proposed new regulatory threshold (> 0.58m^2/100kg)

Lambooy et al (1985) and Pasquale et al (2024a) compared a space allowance above the threshold in the new regulatory proposal (> 0.58m^2/100kg) with allowances complying with the current regulations (0.43 and 0.49m^2/100kg) and found no significant difference in physiological parameters associated with increased activity and/or stress (glucose, haematocrit, lactate, CK).

3.2.3.2.2 Comparisons between space allowances above the current (EU) regulatory threshold (> 0.42m^2/100kg) but below the new regulatory proposal (0.58m^2/100kg)

Higher body temperatures and a slight increase in heart rate suggesting increased activity or stress associated with limited space in the vehicle were observed in pigs transported at the regulatory loading density (space allowance of 0.44m^2/100kg) compared with conspecifics transported at a higher space allowance, slightly below the threshold in the new regulatory proposal (0.56m^2/100kg) (Gerritzen et al., 2013). In pigs transported at two different allowances within the current regulations, ranging from 0.43 to 0.50m^2/100kg depending on the study (Urrea et al., 2021; Pasquale et al., 2024a), no significant difference was observed in stress-related physiological parameters in the plasmas (glucose, haematocrit, lactate, CK). Only Barton Gade & Christensen (1998) observed a decrease in CK concentrations at the highest space allowance (0.50m^2/100kg) compared to an allowance of 0.42m^2/100kg, suggesting less muscle fatigue in pigs transported at a higher allowance. However, lactate

and cortisol concentrations did not differ between groups of pigs transported at these two allowances (Barton Gade & Christensen, 1998). With regard to the lack of effect on plasma cortisol, it should be noted that this is a stress-reactive hormone that peaks during transport regardless of density (Knowles & Warriss, 2007).

The case of piglets

The physiological parameters (cortisol, glucose, immune system) measured during transport in 5kg weaned piglets did not vary at different space allowances (0.05, 0.06 and 0.07m²/piglet) (Sutherland et al. 2009a; Sutherland et al., 2010). In another study, however, the same authors found that the N:L ratio was higher at an allowance of 0.05m²/piglet. This finding, combined with reduced lying behaviours, suggests that this space allowance is not sufficient for the transport of weaned piglets for 1 hour in summer (Sutherland et al., 2009b).

In conclusion: Certain physiological stress parameters (body temperature, heart rate) are lower in pigs transported at an in-vehicle space allowance approximating the threshold in the new regulatory proposal (0.56m^2/100kg) compared with pigs transported at 0.44m^2/100kg. Other parameters (glucose, haematocrit, lactate, CK) remain unchanged. Pigs transported at 0.49m^2/100kg manifested less muscle fatigue (lower CK) than pigs transported at 0.42m^2/100kg, despite similar lactate and cortisol levels.

3.2.3.3 Impacts of space allowance on mortality

It should be remembered that this extreme indicator occurs in serious cases where excessive non-regulatory loading densities have particularly adverse consequences for the animals involved. The two extreme indicators encountered in the literature on pig transport were the mortality rate and the rate of non-ambulatory (tired and/or injured) pigs recorded on unloading at the abattoir (Ritter et al., 2006).

Most ex-post surveys showed a significant positive correlation between high loading density and mortality during transport (Barton Gade et al., 2007; Fitzgerald et al., 2009; Haley et al., 2010). Conversely, only one study reported increased mortality with a higher space allowance (Nannoni et al., 2017). In this study, two categories of loading density were used (high and low), which were assigned on the basis of the number of pigs per compartment but without taking account of weight. The authors concluded that this lack of precision biased their results. Two other studies showed no correlation between pig mortality following transport and space allowances approximating the current regulations (Averós et al., 2008; Marti et al., 2022).

Experimental studies that have calculated percentage losses (mortalities and non-ambulatory pigs) as a measure of the impacts of loading density during the transport of pigs largely compared space allowances below the current regulatory threshold, either with each

other or with an allowance close to the threshhold (Ritter et al., 2006; Ritter et al., 2007; Pilcher et al., 2011) (*Table 2*).

In conclusion: No data is avaliable on the mortality rate of pigs transported at space allowances above the current regulatory threshold. Data collected on space allowances below the current threshold show that the mortality rate of pigs increases when the space allowance is reduced.

3.2.3.4 Impacts of space allowance on meat quality

Meat quality is affected by the physiological and behavioural reactions associated with stress in an animal at the time of slaughter. Here, the underlying mechanisms are those of muscle energy metabolism (Knowles & Warriss, 2007; Terlouw et al., 2015). As for other species, in extreme cases of fatigue and/or stress, pork meat can become dark, firm and dry (DFD) or pale, soft and exudative (PSE) (Adzitey & Nurul, 2011). Physical activity and/or increased stress in the hours before slaughter, for example during a long journey, cause muscle glycogen depletion, resulting in a high final pH (measured 24 hours after death) and a darker meat colour, which is then classified as DFD. On the other hand, physical activity combined with stress in the minutes before slaughter speeds up muscle metabolism and this process continues after death, resulting in more rapid muscle acidification (pH_{45min} <6) and a slower fall in muscle temperature. The meat will then be classified as PSE (Warriss, 2003; Terlouw et al., 2015; Čobanović et al., 2016). Additionally, high skin lesion scores have been recorded for pig carcasses where the meat was graded as PSE or DFD (Guàrdia et al., 2009; Čobanović et al., 2016).

Information on the impacts of space allowance during transport on pork quality has been synthesised by Isbrandt et al. (2022). In general, authors agree that a space allowance lower than or equal to 0.35m^2/100kg during transport has a negative impact on meat quality, with an increased risk of PSE meat (Kim et al., 2004; Guàrdia et al., 2005; Pereira et al., 2015; Čobanović et al., 2016; Urrea et al., 2021) especially when the weather is warm (Hunter et al., 1994) (*Table 2*).

Guise & Penny (1989) showed that a space allowance approximating that in the new regulatory proposal (> 0.56m^2/100kg) reduced the incidence of DFD meat compared with carcasses from pigs transported at a strictly regulatory allowance (0.42m^2/100kg). These authors also observed fewer rectal prolapses (likely to lead to cannibalism) when 100kg pigs were transported at a minimum of 0.42m^2/animal. An et al. (2023) confirmed this finding, showing that pigs transported at a space allowance over 0.43m^2/100kg had a higher carcass weight and better overall meat quality than pigs transported at lower space allowances.

Some authors have however noted that a space allowance over 0.50m^2/100kg increased the incidence of DFD meat (Čobanović et al., 2016). Meanwhile, other studies failed to establish any effect of stocking density during 3-hours journeys on the carcass quality of pigs when

comparing four space allowances ranging from 0.49 to 0.32m²/pig (Warriss et al., 1998; Guise et al., 1998; Barton Gade & Christensen, 1998). Comparing space allowances of 0.42, 0.50 and 0.60m² for 105 and 120kg pigs transported for 36 hours (including a 9-hour break), Chevillon et al. (2003) showed no effect of space allowance per pig on carcass yield, final carcass pH and number of lesions. On the other hand, pigs at the highest space allowance in their study lost less live weight during transport as the result of higher feed consumption (Chevillon et al., 2003).

The sometimes contradictory nature of these results can probably be explained by differences in experimental protocols, especially since systematic account was not taken in each study of certain other intrinsic transport conditions affecting meat quality and welfare (journey duration, driving style, presence of bedding, etc.).

In conclusion: Generally speaking, a space allocation less than or equal to 0.35m²/100kg during transport has a negative impact on meat quality. Studies comparing space allowances above 0.50m²/100kg during the transport of pigs with space allowances below 0.50m²/100kg arrive at contradictory conclusions regarding meat quality.

3.3 Factors potentially aggravating the risk of falls and injuries as a function of space allowance

3.3.1 Types of roads, driving and lorries

Several authors have suggested that higher space allowances in the lorry would lead to a lower risk of injuries, especially severe ones, in pigs during transport, except where road conditions and/or driving quality is poor (Barton Gade & Christensen, 1998; Pereira et al., 2015; Čobanović et al., 2023). Regardless of the loading density on a journey, vehicle driving events such as acceleration (> 0.7 g), braking and cornering, along with rough road surfaces, generate longitudinal, lateral and vertical movements that force pigs to adjust their posture frequently to keep their balance, requiring corrective muscle actions that can cause stress and fatigue and increase the risk of falls (Cockram & Spence, 2012).

How frequently animals lose their balance is influenced by the type of road (Bradshaw et al., 1996b). As observed by Barton Gade & Christensen (1998), poor road surfaces or sharp bends required the pigs being transported to change their posture constantly, leading to difficulties in maintaining their balance at space allowances of 0.42 or 0.50m²/100kg. Randall & Bradshaw (1998) measured greater acceleration on the longitudinal, lateral and vertical when pigs were driven on secondary roads than on main roads or motorways, resulting in loss of balance, knocks to the body and disturbed lying behaviours. On secondary roads some pigs displayed foaming at the mouth and chomping, described by the authors as indicators

of motion sickness. Bradshaw et al. (1996b) reported that during a 'very rough' journey (characterised through reference to an accelerometer), pigs spent more time standing and had higher salivary cortisol levels than during a smoother journey. Similarly, at 0.41m²/100kg, Cockram & Spence (2012) observed more standing behaviour and repeated falls on secondary roads than on the motorway, where fewer driving manoeuvres are called for. Another study showed that pigs on a short journey (63 km with a space allowance of 0.62m^2/100kg) lay down for around 13% of the time when a vehicle-drawn trailer was driven carefully, but lay down for around only 3% of the time when the trailer was driven at a higher speed, resulting in more recorded of accelerations along all three axes (Peeters et al., 2008).

In addition to the types of roads that make up the route, lack of driver experience or training can pose an additional risk to the welfare of livestock during transport (Thodberg et al., 2020). Indeed, Nannoni et al. (2017) found that rough driving increased the mortality rate of pigs during transport. Cockram & Spence (2012) suggested that by anticipating potential driving events (cornering, braking, acceleration) and planning their routes to avoid secondary roads in favour of main roads or motorways, drivers would reduce the likelihood and severity of animal falls. According to Driessen et al (2020), driving style could be improved by specific training programmes.

Last, the use of lorries equipped with a spring suspension system has been shown to have a negative impact on pig welfare, as indicated by increased haematomas and skin lesions on carcasses and reduced pork quality (Dalla Costa et al., 2017). In order to limit vibration, shocks and the associated losses of balance, the authors recommended the use of an air suspension system, reducing impacts on meat quality and stress in pigs being transported to the abattoir. It should also be noted that the extent to which animals perceive vibration and acceleration varies according to their level in the lorry, with pigs on the lower deck being more exposed to vibration than those on the upper deck (Alambarrio et al., 2022). It can also be expected that the location of pigs in the lorry will also dictate the extent to which they are affected by the shocks associated with rough driving that could lead to falls, but the link between location in the lorry and the risk of falls has not been assessed in the literature.

In conclusion: During road transport, driving events (acceleration, braking, cornering sharply) and the type of roads used (secondary roads) are likely to cause stress and fatigue in pigs and also increase the risk of falls. Inexperienced or untrained drivers are an additional risk for pig welfare. The use of lorries equipped with an air suspension system is essential in order to limit shocks and loss of balance in the animals.

3.3.2 Journey duration

The scientific literature shows that the EU loading density requirement should be applied differently according to the length of the trip, since journey duration appears to influence the postures adopted by pigs in the vehicle (Rioja-Lang et al., 2019; Schwartzkopf-Genswein

et al., 2012). Some studies have found that, even when travelling at a space allowance above the regulatory threshold (0.49m^2/100kg), the majority of pigs remained standing during journeys lasting 1.5 hours (Bradshaw et al., 1996b) and 3 hours (Riches & Guise, 1997). Moreover, even on a 3-hour journey, a standing posture was more common at the beginning of the journey than at the end (Cockram & Spence, 2012). Meanwhile, other studies have reported that pigs gradually lay down during the first 2 hours if there was plenty of space available in the lorry (0.64m^2/100kg: Lambooy et al., 1985; 0.50m^2/100kg: Barton-Gade & Christiansen, 1998). Lambooy & Engel (1991) showed that with a sufficient space allowance (0.54m^2/100kg pig), the percentage of recumbent positions increased progressively, reaching 60% after 3 hours of travel. In fact, the seeming contradictions in these results suggest that 3-hour journeys should perhaps not be classed as 'short' journeys. Indeed, although animals might be standing on departure, the above studies were in agreement that the majority of pigs adopted a lying position after 2 hours of transport.

Even for short journeys, a high space allowance limits the fatigue felt by pigs. Indeed, Pilcher et al (2011) showed that increasing the space allowance from 0.40-0.49 to 0.52m^2/100kg reduced fatigue levels in pigs on arrival at the abattoir (less panting and skin discolouration) following a short journey (< 1 hour) compared with 3-hour journeys.

Gerritzen et al. (2013) and Urrea et al. (2021) consider that pigs are better able to adapt to transport conditions lasting longer than 2 hours if they are loaded at a space allowance above the current EU requirement, which makes it possible for them to rest (Lambooy et al, 1985; Lambooy & Engel, 1991; Barton-Gade & Christiansen, 1998), and to avoid having to maintain their balance during vehicle manoeuvres (Barton-Gade & Christiansen, 1998).

In conclusion: Most pigs are standing on departure and then lie down after 2 hours of transport, which could reduce the risk of falls and/or injuries. A journey duration of more than 2 hours would require a space allowance that enabled all pigs to lie down simultaneously in a 'semi-recumbent' position.

3.3.3 Temperature

The impacts of interactions between stocking density and ambient temperature during the transport of pigs has been assessed, but not at the densities indicated in the proposed regulations. When the temperature exceeds 24°C and pigs do not have sufficient space to lie down in a position that will help them to lose heat (CNR BEA, 2025), they become restless and shift postures. In the literature, aggressive behaviours were also more frequent than at a higher space allowance (0.37m^2/100kg vs. 0.43m^2/100kg) (An et al., 2023). Aggressive behaviours were often the cause of injuries observed in pigs following transport (Faucitano, 2001). In winter too, one study reported that an increased space allowance during transport from 0.37 to 0.42m^2/100kg reduced the risk of skin lesions by 6.5% (Guàrdia et al., 2009).

With regard to mortality rates, at environmental temperatures below 21°C, mortality during transport was 2.12 times higher at a space allowance of 0.43-0.44m^2/pig than at > 0.51m^2/pig (Haley et al., 2010). Haley et al. (2010) considered temperature to be a more important determinant of pig mortality during transport than space.

3.4 Actions to mitigate the risk of falls and injuries during transport

+ For training organisations: It is vital to increase the accessibility and specificity of training programmes for transporters of live animals, to include animal handling, recognition of stress indicators, vehicle driving styles and choice of routes (main roads where possible). In particular, training should address all aspects of driving, such as the starting procedure, gentle acceleration and braking, use of engine braking and anticipation of bends in the road. It is therefore essential to train drivers to be more aware of the effects of driving style on the comfort of the animals being transported. Guides to good practice for transporting pigs were published in 2017 by the European Commission (access here) and by the IFIP (in French, access here).

+ For livestock transport companies: When transporting live animals by road, it would be desirable for lorries to be equipped with an air suspension system to reduce vibration, shocks, and loss of balance in the animals. The surface of the transporter's flooring should have an anti-slip coating. It would be desirable for livestock transport companies to routinely offer training to drivers.

+ For producers and transport agents: It would be desirable for a large quantity of bedding (straw or sawdust) to be provided in the lorry for the comfort of the animals and to cushion any shocks when the lorry is in motion. A study has shown that 7.5 L of sawdust per pig for long journeys ensures the cleanliness and comfort of pigs (Chevillon et al., 2003). In addition, by enriching the environment with toys during transport, shoulder injury scores on carcasses could be reduced, in particular by providing plastic balls filled with maize (Peeters & Geers, 2006). Bringing this type of item into the vehicle would mitigate aggressive interactions by occupying the animals that have space in the vehicle.

4 Conclusions and future research

The number of studies that have looked specifically at the impact of loading density on the risk of pigs falling and being injured during transport is too low to provide a precise answer to the question posed. **It is not therefore known whether the suggested space allowance of 0.58m^2/100kg in the new regulatory proposal would increase the risk of falls for pigs during transport. However, no study indicates that this risk exists**.

The injuries observed on pig carcasses following transport can have multiple causes. The smaller the space allowances, the more injuries are associated with aggressive interactions. When injuries occur at higher space allowances, some authors attribute these to falls associated with the wider spacing between animals, although no falls were directly observed. These authors stress that the quality of the ride and road surfaces are factors that increase this risk. Generally speaking, most studies show that **skin lesions and/or haematomas are more frequent when the space allowance per animal is low**. One study in particular found this to be the case when the lowest space allowance was close to the regulatory value (0.42m^2/100kg) as compared with a space allowance approaching that in the new regulatory proposal (> 0.56m^2/100kg). **The literature has therefore not demonstrated any greater risk of injury at the new proposed space allowance than at the current regulatory space allowance.**

The majority of scientific articles have evaluated the effects of different loading densities during transport on the welfare of pigs in general, making use of behavioural and physiological indicators, and on meat quality. Few of these studies have looked at space allowances greater than or equal to 0.58m^2/100kg, the figure indicated in the European regulatory proposal. The FRCAW has nevertheless analysed the results of the four research studies that compared space allowances similar to the proposed new European regulation (≥ 0.56m^2/100kg) (European Commission, 2023) with space allowances in line with the current regulation, ranging between 0.42 and 0.49m^2/100kg. The behavioural and physiological results showed that **pigs transported at a space allowance above the regulatory threshold are better rested during the journey and on arrival at the abattoir.** Pigs with a higher allowance were more frequently observed lying down and were quicker to lie down after leaving the lorry. Their body temperature and heart rate measured during transport were lower at the higher space allowance, although some studies found no effects of loading density on the physiological parameters measured. The results relating to meat quality were contradictory, depending on the study. Since transport is a multifactorial event, the interactions between loading density and other factors (ambient conditions inside the vehicle, journey duration, vehicle type, driving style, etc.) were not systematically assessed by all studies, a fact that may explain the differences in the results.

Regarding the transport of weaned piglets, no study has assessed the risks of falls and injuries in relation to the space allowance. However, some authors were of the view that space allowances above the regulatory minimum allowed piglets to make a choice (whether

to lie on top of each other or in contact with the ground), and that this would reduce the stress of transport.

In a transporter, it is important for all the pigs to be able lie down to rest, but also to provide greater stability during driving events. According to the EFSA's opinion, a suitable loading density would allow all the pigs to lie down in the 'normal semi-recumbent' position simultaneously. An even higher space allowance would be required in hot weather to allow all the pigs to thermoregulate by lying completely stretched out on their sides in contact with the floor, which is not possible at an allowance of 235kg/m^2, corresponding to the current regulatory threshold. Furthermore, at the start of a journey, pigs would appear to prefer to stand, only lying down around 2 hours after departure. **For journeys more than two hours long, pigs therefore need more space, both to lie down in order to rest and thermoregulate and to access drinking troughs inside the vehicles. The space allowance allocated to the pigs should therefore be adjusted according to the ambient temperature and journey duration**.

Further research

- It is essential that more targeted studies should be conducted, incorporating the use of cameras in the lorry, in order to observe the actual movements of pigs and any falls that may occur in a moving vehicle as a function of loading density.
- Studies comparing space allowances in line with the current regulations with that proposed in 2023 by the European Commission, and examining their respective impacts on pig falls and injuries during transport, are needed.
- It would be of interest to conduct studies comparing the behaviours (particularly posture) of pigs during the first two hours of transport with the hours that follow as a function of the space allowance in to determine precisely how the animals' fatigue and space requirements change during transport.
- As transport is a multifactorial event that can affect pig welfare, further studies on the impacts of loading density and its interaction with factors such as ambient conditions inside the vehicle, journey, type of vehicle, length of journey breaks and the management of pigs during breaks are required.
- More specifically, it is essential to continue research into the welfare of pigs during transport at all stages, as a pig's needs vary during its lifetime. Not only finishing pigs, weaners and breeding pigs, but also cull sows and boars should be studied.

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